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Rice.

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RICE

1. Typical terraced paddy field near Kandy, Ceylon

RICE

by

D. H. GRIST
DIP. AGRIC. (CANTAB.)

Formerly Agricultural Economist,
Colonial Agricultural Service,
Malaya

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INTRODUCTION

by

Sir Harold Tempany, C.M.G., C.B.E., D.Sc., F.R.I.C.
Formerly Agricultural Adviser to the Secretary of State for the Colonies

THERE is no more important crop in the world to-day than rice; it is the staple food of the teeming millions of south-east Asia, whose numbers are increasing rapidly. Even before the war rice supplies barely sufficed to satisfy their needs at a rather substandard level of of subsistence; to-day populations in these regions have already increased by over 10 per cent beyond the pre-war level, while production only slightly exceeds that of the pre-war years. The increase of rice production is one of the major world agricultural problems; upon its solution world peace and security are largely dependent.

The urgency of the matter has induced the United Nations, acting in conjunction with the Food and Agriculture Organization and other associated bodies, to set up the International Rice Commission. A large part of the activities envisaged under the Colombo plan are also concerned with the augmentation of rice production in certain Eastern countries.

In such circumstances a work dealing with the various aspects of rice production is obviously badly needed. So far as I am aware the only book on the subject is E. B. Copeland's work published nearly thirty years ago. Since that was written, however, there have been a number of important changes and developments in the situation. Accordingly the present work by Mr. D. H. Grist is timely. He spent many years in the Far East where for a long period he served as Agricultural Economist in the Malayan Department of Agriculture, where I was closely associated with him as a friend and colleague. So he is intimately acquainted with rice production under Eastern conditions. Moreover, he has also recently visited certain countries in South America where rice is grown. He is thus well qualified to undertake the compilation of this book. In it he has collected and

summarized a large amount of information drawn from numerous sources concerning the characteristics of the crop, its irrigation, cultivation, and manuring, the pests and diseases which attack it, and its milling and processing. In the concluding chapters he has discussed factors which affect production and the prospects of increasing it. Throughout he has also drawn largely on his wide experience.

It is hoped that the book will serve a useful purpose by bringing within the compass of one volume reasonably full and up-to-date information concerning this vastly important and in some respects unique cereal.

7 North End House
London, W.14.

H. TEMPANY

NOTE

This volume is one of a series of books on tropical agriculture which are being published with the active encouragement of the Colonial Advisory Council of Agriculture, Animal Health and Forestry, under the editorship of Sir Harold Tempany, C.M.G., C.B.E., formerly Agricultural Adviser to the Secretary of State for the Colonies and previously Director of Agriculture in Mauritius and Malaya.

Other volumes in preparation:
Tropical Agriculture, by Sir Harold Tempany.
Cocoa, by D. H. Urquhart.
Tea, by T. Eden.

PREFACE

RICE is perhaps the most remarkable of cultivated crops, for although possessing the roots of a dry-land plant, it flourishes in swamps or under irrigation, and in Asia has produced one or more crops annually for centuries. This continuous rice growing—almost unexampled in the crop world—produces yields at a surprisingly high level, despite the fact that in many regions the land is never manured.

The crop is grown over a very wide range of climatic, soil, and water conditions, from wet tropical to regions of semi-arid, warm temperate climate; in heavy clays or poor sandy soils; on dry land or in swamp land in water that may be fifteen to twenty feet deep; in fresh or in brackish water. The thousands of varieties of rice that exist account for this cosmopolitan nature, for it is true to say that a variety may be found to suit almost any condition, provided that the plant is subject to abundant sunshine and given water sufficient for the requirements of the particular variety.

While rice is not a complete food in itself, as a grain it has a very high nutritive value, second only to wheat. Unfortunately, much of these nutrients (proteins, fats, and water-soluble vitamins of the B complex) are eliminated in the processes of milling and cooking. Many of the diseases suffered by rice-eaters are caused by malnutrition and are preventable by such means as improved milling, parboiling, and cooking, by which the vitamins in particular are retained in the finished product. Improvements in health are already evident in some countries as a result of the application of scientific research into this subject.

It is estimated that an annual increase of 1·3 million tons of rice is necessary to meet the needs of the growing rice-eating population. While, of course, the ultimate solution of the problem of meeting demand by supply must be by the curtailment of population increase, the immediate necessity for larger rice supplies may be met by an increased area under the crop and by improved yields. If the price of rice is maintained at a high level, the area may be expected to increase in many countries, the chief deterrent to development being the high cost of bringing land into cultivation.

The possibility of improved productivity is discussed in some detail in the following pages. The four main channels leading to improve-

ments in yield appear to be, in order of importance: improved drainage and irrigation; more effective control of pests; the addition of humus to the land, with or without fertilizers; and the selection and breeding of varieties.

Drainage and irrigation are of paramount importance; efficient water control results in a direct improvement in yield; in addition, it aids in the control of pests, diseases, and weeds, and renders fertilizers more effective.

The losses caused by pests are enormous, and largely preventable; for this reason the necessity for better control over pests is given priority over manuring or the improvement of varieties. It is possible that the new and very potent insecticides now on the market may prove of value against certain pests of the rice crop which hitherto have been difficult to control.

It is usual to assume that increased yields will result from fertilizing the crop. While some improvement may be expected by this means, it is probable that undue emphasis has been given in some quarters to the need for fertilizers. The requirement of first importance in many areas is humus, with or without the addition of fertilizers. It is probable, therefore, that by such means as green manuring, fallowing, rotation of rice with a grass ley, and cattle grazing, the application of fertilizers on a more modest scale may be found sufficient, while in many areas fertilizers may be found unnecessary.

Considerable research work has been done towards the improvement of varieties and in the study of varieties in relation to their environment. This will, for a long time, be a fruitful line of research, leading to the production of varieties resistant to particular pests and diseases, and capable of producing optimum yields under varying conditions.

Rice is intimately bound up with the economy and well-being of Asia. The total area under the crop exceeds 200 million acres, of which over 90 per cent is grown in Asia. Yet the demand for rice in Asia exceeds present world supplies. It is the staple diet of over half the world population, including countless millions in Asia who subsist almost entirely on rice. If, therefore, in the following pages the author appears to have laid undue stress on rice in Asia, his defence is the urgency of the many problems as they affect the life of an immense population that lives very near to starvation, and which is sustained almost entirely on rice.

D. H. GRIST

Stoke-by-Nayland
Suffolk
August 1951

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In writing this book during the past four years, I have corresponded with many rice experts in this and other countries, have visited libraries, have abstracted or made use of abstracts prepared by others, and have shamelessly importuned all who were in a position to give me information or advice. Invariably I have been treated as a colleague to whom one willingly gives every help and encouragement. While this attitude towards me has rendered my task very pleasant, it makes my acknowledgements in this place very difficult, for to include all who have helped me with information, advice, criticisms, illustrations, or who have read my manuscript would make a lengthy list, which would still inevitably omit some whose research work has either directly or indirectly assisted me. To all these I tender my respectful thanks.

In the appropriate places throughout this book I have endeavoured to acknowledge and do justice to the research work on rice. There can, however, be no finality to a book such as this. I am constantly coming across both old and new work to which I should make reference. The subject is such a wide one, and the literature on it so scattered, that mention of important research work may have been omitted from this book. I can but offer my apologies for such omissions both to the scientists concerned and to my readers.

I gratefully acknowledge the very great assistance I have received from Dr. G. Watts Padwick and Mr. E. J. McNaughton, both of Imperial Chemical Industries, in connection with the chapters on Diseases and Pests respectively; from Mr. H. T. Pagden, Senior Entomologist, Malayan Department of Agriculture, in connection with the chapter on Pests; from Dr. J. C. Hinton of the Cereal Research Station, St. Albans, in connection with the chapter on Nutrition. I am also indebted to Mr. J. M. Hector for extensive use made of his work on the botany of rice, and to Mr. Ng Beng Cheng of the Malayan Department of Agriculture for his excellent drawings of insect pests.

In the preparation of this book I have unfailingly received encouragement and wise guidance from my former chief, Sir Harold Tempany, C.M.G., C.B.E.; I am deeply grateful for all the help he has given me.

Finally, I am also most grateful for the encouragement and help of my wife, not least for being the kindly critic who has prevented me from perpetrating many errors.

D. H. Grist

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Chapter I

THE ORIGIN AND HISTORY OF RICE

Rice has been cultivated for such countless ages that its origin must always be a matter for some conjecture. Botanists base their evidence as to its origin on the habitats of the wild species. There are about a dozen species of *Oryza* found in Asia, Africa, and South America, the genus being particularly strongly represented in Africa. It is presumed that the cultivated species have developed from certain of these wild rices; it is possible, but by botanists considered unlikely, that certain of these wild species are descended from cultivated rice.

Burkill[35] states that "man can have invented the wet rice-field only after he had long grown rice as what is called a dry-land crop. The parts of the world, therefore, where it is so grown, taken together with the physiological requirements of the parents, indicate within what rather wide limits wet-rice cultivation must have arisen. The Asiatic species which have been pointed out as parents—*O. fatua* and *O. minuta*—occur in moist places from the Eastern Himalaya to Ceylon and from the southern-most edge of China through Burma and Indo-China to Java, Borneo, and the Philippine islands; and where they grow, dry-land cultivation is practised. It would be between these limits that the first wet-rice cultivation was undertaken." *O. punctata* Kotschy, states Bain,[15] occurs wild in rain-flooded depressions in the Sudan, its seeds as well as that of other wild species still occur and are harvested in times of shortage.

The nearest wild plant to cultivated rice is *Oryza fatua*, which is found wild throughout south-eastern Asia as far as Java. Of this species Burkill writes: "In the fields of south-western and western India it is exactly like the annual *O. sativa* in every respect except that it shatters at maturity. In the Gangetic plains it is seen in a different form, but it is still like *O. sativa* except for shattering. The poor do not ignore it, but tying the awns together before maturity save the grain for themselves, or they collect the fallen grain, which is made an easier process by the length of the awns." It is considered probable that the majority of forms of cultivated rice have originated from this species. The small-grained varieties of rice have originated from *O. minuta*, which in Asia is cultivated, the crop

of minute seed finding a specialized market for the feeding of small cage birds. Some of the African varieties are attributed to *O. breviligulata* A. Chev & Rochr., and *O. glaberrima* Stend. Some of the indigenous cultivated rices of Nigeria are varieties of *O. glaberrima*, but due to their dark colour and inferior quality grain, they have been largely replaced by the white-grained varieties, except in the less fertile parts of the country.

Copeland[51] adds linguistic evidence to the botanical evidence to prove that rice originated in south-east Asia. "Rice," he states, "was not a crop of the Egyptians or Chaldeans in very ancient times. It is therefore improbable that its culture originated in Africa and spread thence to Asia, a possibility which the botanical evidence would admit." He points to the fact that in Chinese and many other languages in south-east Asia, agriculture and rice or food and rice are synonymous, pointing to the conclusion that paddy was first cultivated in this part of the world.

Paddy cultivation probably dates back to the earliest age of man, and long before the era of which we have historical evidence it was probably the staple food and the first cultivated crop in Asia. Earliest historical references are found in Chinese writings of about five thousand years ago, when it was stated that the privilege of sowing paddy was reserved for the Emperor alone, the less important cereals being reserved for the less exalted members of his family. It should not be assumed, however, that the crop originated in China, for while wild rice is found in many countries of south-east Asia, it has not been recorded from China. Ramiah[193] points out that the original homes of plants are characterized by the great diversity of forms, rich in varieties, and it is in south-east Asia, India, China, and Indo-China that this great diversity is to be found. All the Hindu scriptures mention rice, and all offerings to God are given as rice, denoting its antiquity. Ramiah adds that some of the very ancient Tamil *puranas* contain descriptions of particular varieties of rice which are to be used in certain religious offerings, showing that even in those ancient times varieties with definite grain characteristics were recognized. This religious aspect has persisted throughout the ages in Eastern countries, for it enters into the religious rites in Borneo, while in Java rice is considered as the offspring of the goddess Dewie Srie. Usually the religious significance is connected with fecundity and plenty. Rice cakes are eaten at certain festivals in Asia to symbolize long life, happiness, and abundance. The custom at weddings in Europe of throwing rice at the bride and bridegroom is obviously borrowed from the East.

According to Chi[46] the first authentic record of irrigation for paddy

cultivation is to be found in the *Book of Poetry* supposed to have been written in the Chow dynasty about 781–771 B.C., wherein the writer refers to water flowing northwards from the river to the rice-fields in the Wei Valley of Shensi. The historian Ssu-ma Ch'ien in 148 B.C. wrote of conditions in the Yengtze Valley, "where the land is tilled with fire and hoed with water," which is held to refer to the burning off of trees and undergrowth, flooding the land, and planting paddy.

We do not know the country of origin of rice, but the weight of evidence points to the fact that it originated in the continent of south-east Asia, spreading northwards in Asia before the later movements of the Aryan dispersal, for the name is alike in Zind and Sanskrit, and similar in Old Persian. From the mainland of the continent it also spread south and east through the Malay archipelago with the flow of human culture. It was introduced into Indonesia by the Deutero-Malays when they immigrated there about 1500 B.C. The legend that paddy cultivation was introduced by the Hindus has been disproved.[157]

In Ceylon, paddy has been grown from time immemorial. Before about 543 B.C. it was probably grown on the island as a dry-land crop. The earliest references to tanks to conserve water for irrigation of paddy in Ceylon are about 420 B.C. While some of these tanks were undoubtedly used to supply water for domestic purposes, it is certain that a network of tanks to supply water for paddy cultivation was built up from the time of the early Sinhalese kings. During the subsequent invasions these irrigation systems were severely damaged, while malaria so reduced the population that the cultivation of paddy rapidly declined. It is of present interest to note that many of these ancient tanks have been repaired and are again doing good service for the purpose for which they were originally intended some thousand or more years ago. It is thought, however, that the area cultivated with paddy in Ceylon may now be very much less than in ancient times. It has been suggested that in early history the island became the granary of the East and that an export trade in rice developed with neighbouring countries.[184]

Paddy cultivation is of great antiquity in the Philippines. It is thought that the wonderful system of terraces on the mountain-sides in the island of Luzon was constructed by an immigrant people from south China in the second millennium B.C. These people were driven into the hills by subsequent invasions of Malayan people. The present-day cultivators, said to be descendants of the original Ifugao immigrants, continue to cultivate this crop by methods brought down to them through thousands of years.[281]

Rice did not reach western Asia and the highly civilized Egypt, Greece, and Rome until much later. No references to rice are found in ancient Egyptian tombs or writings, ancient Persian writings are silent on the subject, while no mention is to be found in the Bible. On the other hand, the Talmud, at a later date, refers to the cultivation of rice. The Greeks learned of rice from the Persians, and medieval Europe got it from the Saracens. Theophrastus, born about 375 B.C., refers to the cultivation of paddy in Egypt, and the Greek historian Diodore of Sicily, a contemporary of Augustus, describes the plant and its cultivation from reports made to him by Aristobule who took part in the expedition of Alexander the Great to India *circa* 344–324 B.C. Rice was therefore known to the ancient Romans as a result of their conquests in the East, and its cultivation in Sicily may have existed in very early times.[250] The crop was introduced into northern Italy in the fifteenth century, the first authentic mention of its cultivation in this region occurring in a letter written by the Duke of Milan in 1475.[173] During the time of the Roman Empire rice was imported, and it was not cultivated in the Mediterranean basin until the Arabs introduced it in the Nile Delta. The Malays are said to have brought the crop to Madagascar and the Indians to the East African islands. The Moors brought rice to Spain, the Spaniards brought it to Italy, and the Turks introduced it over much of the south-eastern part of Europe.

The Portuguese introduced rice into Brazil and the Spaniards into central America and parts of South America. It was introduced into Hawaii in 1853; the French brought it to New Caledonia and the Germans to New Guinea.

The introduction of paddy cultivation into the United States dates to about 1685 when it was introduced into the colony of South Carolina, probably from Madagascar. About 1718 it was introduced into Louisiana, but it did not assume importance in that State till 1887, when it was determined that the crop could be profitably grown by mechanization on the prairies in the south-western part of the State. This State then became, and still is, the leading State in rice production. The commercial rice crops of the United States are now grown almost entirely in the State of Arkansas, where it was introduced early in the present century, California, where the first commercial crop was grown in the Sacramento Valley in 1912, Louisiana, and in Texas. In the last-named State, dry-land paddy was probably grown as early as 1863, but it did not assume any importance until some thirty-five years later, when irrigated paddy was successfully introduced.

Unsuccessful attempts were made to develop paddy cultivation

in British Guiana early in the eighteenth century. It was not until 1886 when, using irrigation facilities for a sugar estate and employing East Indian and Chinese labour with a knowledge of methods of cultivation, the crop was successfully grown.[198]

Paddy has been successfully grown on a commercial scale in Australia since 1924, but as early as 1891 farmers in New South Wales tried to grow dry-land paddy without success. Further trials with wet-land paddy were equally unsuccessful, because unsuitable varieties were planted. The development of the Murrumbidgee Irrigation Area finally established the crop on a firm basis.[111]

In addition to the authorities acknowledged, use has been made of information contained in *A Dictionary of the Economic Products of the Malay Peninsula*, by I. H. Burkill; *The Rice Economy of Monsoon Asia*, by V. D. Wickizer and M. K. Bennett; *Rice*, by E. B. Copeland; "De Classification Botanique des Riz Cultures," by G.-G. Gushchin, and in official publications of the U.S.A. Department of Agriculture.

Chapter II

CLIMATE AND SOILS

Climate—Soils—Acidity of Soils—Salinity in Soils—Some Paddy Soils—Conclusion.

CLIMATE

THE paddy plant will flourish under such widely differing conditions that it is difficult to define the climate that is most suitable for its development. "Rice," states Pendleton,[189] "is doubtless the most adaptable food crop man grows, and if enough water remains on the soil until the maturing of the crop, it can produce at least a little grain on soils that are unbelievably poor in plant nutrients."

Evidence is advanced in Chapter XVI showing that the highest yields are obtained in countries enjoying a sub-tropical or warm temperate climate. It is certain that paddy thrives over a wide range of climatic conditions within 40° latitude north and south of the Equator. Generally looked upon as a crop suited to the wet tropics, where indeed the greater part of the total area is situated, nevertheless it flourishes in such countries as Egypt and Australia, and among temperate climate localities in Spain, Portugal, and Italy. If, in fact, the assertion is true that it will grow within 40° of the Equator, the area embraced by this includes Central America, half of the United States, the West Indies, most of South America, the entire continent of Africa, the whole of Australia, India, most of China, Japan, the Malay Archipelago, and the Pacific islands. The conclusion is evident that within the stated range of latitude (excluding the high mountainous regions) the chief limiting factor to its growth is water supply. Compared with water supply soils are relatively unimportant.

One of the main reasons for this wide range of climatic conditions under which the crop will grow is the great diversity of varieties of paddy. Much study remains to be done regarding the climatic and other conditions favoured by different varieties, but observations in many countries have sufficed to point to the importance of the study of the suitability of varieties for particular environments. In the first place, varieties differ greatly in their resistance to drought and flood-

ing, some being drought-resistant while others are flood-resistant; some varieties must be grown in fresh water while others will tolerate brackish water. Parallel differences are recorded concerning temperature; while some demand a high temperature, others will grow under much cooler conditions. Graham[87A] records a variety grown in the Central Provinces of India that is generally grown in January and harvested in March. This, he states, is the only cold-weather variety reported in the Central Provinces. The climatic conditions under which paddy is grown in Japan vary enormously, varieties having been found suited to this wide range of climatic conditions.

Copeland[51] is of opinion that high temperature is unlikely to injure the growing crop unless the water is insufficient, and mentions a temperature of 37 to 40° C. as unlikely to harm the plant for such duration as is likely to occur in the field.

It is very certain that whatever the range of climatic conditions the plant will tolerate, it will not flourish unless it is subjected to long periods of sunshine. One authority[17] asserts that the limiting factor is sunlight, especially during the first two months of growth, when temperate paddy-growing countries such as Italy, Spain, and parts of Japan have more sunshine and longer days of daylight than have the tropical countries. Shade has also been observed greatly to retard the attainment of the "critical" stage of tiller formation.[11] So adaptable is the paddy plant, however, that at least one variety is known[193] which in Malabar grows successfully in shade under trees.

In the United States the opinion is held[79] that, particularly during the early stages of submergence, it is important that the water should be reasonably clear. Discoloured water, or water on which there is a scum, prevents sunlight from reaching the submerged seedlings, which are thereby weakened. Furthermore, it is claimed, scum often prevents the seedlings from emerging; rain will cause the scum to precipitate, and if the seedlings are under the scum at the time of precipitation, they usually fail to emerge.

SOILS

The types of soil suitable for paddy cultivation depend more on the conditions under which the plant is grown than upon the nature of the plant. The semi-aquatic conditions under which it is cultivated necessitate a heavy soil through which the irrigation water will not easily percolate, for the demands of the plant as regards water are more precise than are its demands on soil conditions. On most areas during certain times of the year it is essential to conserve water on the land owing to uncertain future supplies; loss of water

through free percolation may therefore be serious at a critical point in the development of the plant. Furthermore, in many areas great reliance is placed on water provided by special irrigation works; such water may be expensive and is usually not available in unlimited quantities.

Most of the extensive areas in Asia are situated in the deltas of great rivers, or are spread along their banks. Thus, the situation of the paddy areas is governed rather by considerations of water supply than by the nature of the soil. It is probable that for this reason there is a paucity of literature on the subject of paddy soils, and that relatively little work has emerged on this aspect of rice production. It has been concluded by some writers that paddy apparently makes no special demands regarding soil, but though this may be in part true —or what is more likely, types of paddy have been found particularly suitable for certain types of soil—the influence of soil characteristics must be of importance, not alone when related to the requirements of the crop, but also in conjunction with the response to manuring.

Apart from the desirability of growing the crop on a heavy soil capable of holding water on the land, there appears to be direct evidence that it grows better on heavy clay soil than upon the lighter soils containing a higher proportion of sand. Provided that sufficient water is available to maintain irrigation, satisfactory yields are frequently obtained on quite sandy soils when they are given heavy dressings of organic matter, and frequently, too, if they are given fertilizers. While, however, exceptional circumstances may determine the suitability of a soil for paddy cultivation, there appears to be no doubt that the heavier types, especially if they contain a satisfactory amount of organic matter, are most suited for paddy growing, and most good paddy-yielding areas will be found to consist of a soil wherein the finer particles—clay plus silt—is high, being generally about 70 per cent.

The chemical analysis of a soil does not appear to provide a very sure guide as to its suitability for paddy cultivation. The fact that soils may be made to produce satisfactory paddy crops annually for centuries shows that the case is not one that can find a parallel in agriculture. Thus it is that paddy soils are found to be very dissimilar in chemical constitution, yet yielding equally good crops.

ACIDITY OF SOILS

It is noted that good paddy soils are almost invariably acid in reaction, the pH value usually varying from about 4 to 6, the nitrogen content from 0·1 to 0·6 per cent, and phosphoric acid from 0·04 to

2. Paddy fields in Thailand

3. Paddy fields north of Bandoeng, Java

4. Terraced paddy fields in southern China

5. Terraced paddy field in Java

6. Typical paddy fields showing terrace cultivation in Burma

7. Paddy fields in Bihar

8. Paddy fields on terraces with stone embankments, Orissa

9. Paddy fields in Peiping. The Summer Palace is in the background

0·17 per cent. Thorp[252] has related soil reaction and salinity to crop yields in China. While admitting that the figures of yield on the saline soils are based on insufficient data, he gives the following results of yields (lb. per acre): 2,678 from soils pH below 6·5; 2,614 from neutral soils with pH 6·5 to 7·5; 2,320 from saline alkaline soils pH above 7·5; and 1,920 from non-saline alkaline soils pH above 7·5. The figures appear to confirm results elsewhere that while paddy is tolerant of considerable variation in soil reaction, it does appear to show a preference for the acid types. Most of the highly productive paddy soils of China are either slightly or strongly acid. In India, Bal and Misra[16] found that the light rich soils in the area of their investigations had a lower pH value than the heavy soils, and add that the paddy plant prefers a slightly acidic or neutral medium to an alkaline one. In Malaya, Grantham[89] stated that there is no apparent connection between the fertility and the acidity shown by the lime absorption, in fact, the best paddy lands, he concluded, are the most acid. Examining the cause of unproductivity of a certain volcanic soil for paddy in Japan, Kamoshita[130] found, as a result of pot experiments, that the alkaline reaction of the soil is harmful to paddy during the first period of growth.

The pH of a paddy soil has a profound influence on the uptake of mineral elements and also on the characters of the root system, and it is significant that the soil around the paddy plant stools, according to Itano and Tsuji,[119] is less acid than elsewhere. Aoki[10] found that the solubility of soil phosphate increased when the reaction changed beyond the range of pH 5 to 7. The degree of increase was larger under paddy-field conditions than under dry-land conditions. The same writer also found[9] that when the soil was flooded before the addition of nitrates, the reduction decreased rapidly; the reduction of nitrates was somewhat increased by stirring the soil before the addition of nitrates and was decreased when the soil was kept at pH 5 for two weeks before the addition of the nitrates.

The pH of a paddy soil, however, is not static. Dennett[66] showed that paddy soils in a flooded condition and during fallow showed large differences in pH value, changes being from pH 4·5–5·0 to 6·5–7·0, the reverse occurring as soon as the irrigation water is run off. In Louisiana[197] the pH of virgin soil in flooded condition increased; with cultivated soil the pH was higher to begin with, but still increased with flooding. The pH showed a tendency to rise in the presence of organic matter.

Fertilizers applied to the soil may change the pH value of the soil to a considerable degree. Long-continued application of ammonium sulphate increases acidity and decreases the content of bases.[279]

Bal and Misra[16] found that the pH value of the soil is lowered by an adequate application of sulphur.

Studies by Bartholomew[25] to estimate the effect of irrigation on the pH of paddy soils showed that calcium, iron, and alumina and the pH of water used caused reversion of large amounts of soil phosphate. Irrigation also induced alkalinity in the surface of the soil. The same writer also found[24] that the use of water containing a high proportion of bases renders added phosphate unavailable.

SALINITY IN SOILS

Proximity to the sea resulting in occasional flooding of the land with sea water results in salinity of the soil. Certain varieties of paddy will flourish in a saline soil, but the majority of varieties are adversely affected by salt. Pendleton[190] states that during the first few years that paddy is grown in the saline coastal clays of Thailand, the growth of straw is luxuriant, but the yield of grain is low and of poor quality. The effect of sodium chloride at different concentrations on the growth of paddy has been studied by Del Valle and Babé.[64] In pot experiments using clay loam soil, paddy plants 30, 60, and 90 days old were subjected until 164 days old to one of five concentrations of sodium chloride (0·15 to 1·0 per cent), the pH remaining at 7. The treatment retarded flowering by 5 to 15 days, and the salt content of the plants varied directly with the salt concentration and length of irrigation from 0·25 per cent in the control without salt to 6·21 per cent in the 30-day plants subjected to a 1 per cent concentration. Concentration of 0·15 and 0·25 per cent greatly lowered the number of grains produced by the 30- and 60-day groups respectively; 0·25 and 0·35 per cent decreased grain size with two groups, while 0·5 per cent prevented grain formation and killed some plants in 60 to 110 days. Ninety-day plants were hardly affected by the concentrations used. Symptoms of sodium chloride toxicity are darkening of the green colour, withering of leaf tips, yellowing, and death.

Cultivators in Thailand[190] classify saline soils as bitter, salty, and sour, others referring to certain soils as astringent. The experienced cultivator can decide on the suitability of the water on his land by taste, while others use betel juice, spitting some of the red mixture into the water standing on the field. If the colour remains red, the water is considered safe for planting; if the colour turns black the water is considered "sour," and planting is delayed.

In Burma, Thailand, Malaya, and British Guiana, and in some other regions, paddy is grown on certain coastal areas of clay, in

some cases reclaimed from the sea or from old mangrove swamps, the soil being a blue, greasy-feeling clay of considerable depth, which turns to a grey-blue colour on exposure. When the salt has been washed out of such soils and they are aerated, they grow excellent crops. Salinity of soil has also been noted in Egypt (see page 145), successive flooding being resorted to with success to rid the land of excess salt. High yields are obtained in British Guiana, the crop being cultivated on the coastal areas characterized by the prevalence of heavy, sodium-magnesium sea-borne clays. Such soils may be alkaline, but with cultivation they become acid, a change which is ascribed to the washing out of the salt by irrigation water. While the soils are satisfactory as they are of considerable depth and reasonably rich in plant nutrients, they are, however, peculiarly susceptible to drought, due, it is said, to shrinking and packing of the soil on drying and to their high content of salts which induces physiological drought. They therefore benefit considerably from periodic submergence and this has led to a system of "flood fallowing" for periods varying from four to twelve months. "The beneficial effects are attributable to washing out of injurious salts, combined with an improvement in soil texture apparently consequent upon an increase in the 'available' iron content of the soil which tends to aggregate the finer soil particles."[203]

This system of flood-fallowing in British Guiana is now a unique feature of sugar-cane cultivation in the colony, in which connection it has been shown to be responsible for an increase in yield up to 40 per cent spread over three years. Investigations show that the effect is associated with an increase in the ammonium nitrogen content of the soil (equal to a dressing of 2 cwt. sulphate of ammonia to the soil), and improvement in texture ascribed to the formation of a hydrophobic film of ferric oxide on the colloidal particles, and to an increased activity of micro-organisms concerned with the supply of plant nutrients.

SOME PADDY SOILS

The following notes are intended to give a generalized account of the soil conditions obtaining in some of the more important rice regions. With the information available it is not possible to correlate these soil analyses with yields, the data being insufficient for this purpose.

Bruce[32] carried out analyses of paddy soils from various Asiatic countries to compare them with the paddy soils of Ceylon. He gives the following "average" of analyses from each area. (See Table 1.)

TABLE I

COMPARISON OF PADDY SOILS FROM CEYLON AND OTHER COUNTRIES
(percentage)

Country	*Coarse*	*Silt*	*Clay*	*Water absorption*	*N*	*CaO*	*MgO*	K_2O	*Citric* K_2O	P_2O_5	*Citric* P_2O_5
Ceylon	63	24	7	48	0·184	0·285	0·351	0·314	0·160	0·114	0·012
South India	52	29	10	51	0·070	1·398	0·801	0·618	0·019	0·169	0·017
Burma	14	55	21	66	0·112	0·600	1·127	0·921	0·016	0·188	0·012
Malaya	34	48	11	71	0·132	0·270	0·438	0·008	0·008	0·074	0·005
Thailand	8	48	27	60	0·248	0·270	0·280	0·131	0·014	0·047	0·007
Philippines	45	34	13	60	0·098	1·880	1·001	0·405	0·016	0·109	0·015
Japan	52	32	10	58	0·179	0·465	0·288	0·431	0·017	0·176	0·017

The detailed chemical analysis of paddy soils studied by Bruce still further accentuates the wide differences to be found in soils considered satisfactory for paddy cultivation. (See Table 2.)

Graham[87] states that the rice-producing soils of the Central Provinces of India are formed almost entirely upon pre-Cambrian rocks of the Purana and Archaean groups. The actual material derived from the weathered rock is greatly modified in many cases by rain-wash and admixture with soils of other types. "The typical rice soils of the Central Provinces have a high proportion of coarse particles and a correspondingly low proportion of clay, being suitable only for single cropping. The heavier soils suitable for double cropping are much finer in texture and therefore more retentive of moisture."

This attempt to relate type to suitability for double cropping is interesting. It would appear that the requirement is a "nice" balance between sand and clay, but it would be dangerous to assume that these requirements for double cropping are applicable to conditions in other countries, for the factors relating to double cropping are too diverse to be settled on the soil factor alone. Graham's observation is a valuable one and should be related to the soil analyses of areas where double cropping is customary. (See Table 3.)

Pendleton[190] has described the formation, development, and utilization of the soils on the Bangkok Plain of Thailand, a low flat area with dark, grey clays, with rather higher land along the western, north-western, northern, and north-eastern parts, where the soil is

TABLE 2

CHEMICAL ANALYSES OF SOME ASIATIC PADDY SOILS
(percentage)

	Moisture	*Organic matter and combined water*	*Oxide of Fe and Mn*	*Oxide of alumina*	*Lime*	*Mg*	*Potash* K_2O	*Soda*	*Sulphuric anhydride*	P_2O_5	*Chlorine*	*Silica*	*Containing nitrogen*
Galle District of Ceylon	3·000	13·340	4·240	24·026	0·200	0·087	0·154	0·337	0·123	0·128	0·035	54·330	0·230
Rich soil in C.P. India	3·340	14·720	13·760	17·554	0·180	0·230	0·378	0·509	0·096	0·141	0·012	49·080	0·235
Coimbatore District of India	5·400	4·200	4·000	11·738	0·940	1·325	0·942	0·525	0·014	0·154	0·012	70·750	0·056
Pegu District of Burma	4·800	7·800	6·720	11·780	0·440	1·210	0·903	0·515	0·069	0·205	0·038	65·520	0·134
Krian District of Malaya	6·200	9·600	2·400	14·034	0·400	0·490	0·695	0·816	0·233	0·077	0·086	64·770	0·140
Alabang, Rizal, Philippines	5·200	7·400	7·040	13·604	1·040	0·677	0·347	0·769	0·069	0·102	0·012	63·740	0·101
Rangsit District of Thailand	6·070	13·650	1·530	5·400	0·260	0·240	0·106	—	0·810	0·514	—	—	0·434
Tokyo Chiba Prefecture, Japan	2·200	10·880	6·720	9·342	1·041	0·432	0·270	0·579	0·110	0·230	0·027	68·170	0·286

younger and of a light greyish-brown to light brown silt loam to light clay loam. These latter soils, he states, are less intensely cultivated, producing mostly upland crops, but when irrigated are superior paddy soils. The writer concludes that the soils of this vast plain exemplify many stages in the development of laterite from river-borne alluvium. Some stages are marine clays, young clays producing good paddy, mature and less fertile clays, senile unproductive soils, and laterite.

TABLE 3

COMPOSITION OF TYPICAL PADDY SOILS IN THE CENTRAL PROVINCES OF INDIA
(percentage)

	Soils				
	1	2	3	4	5
Coarse sand 1 to 0·2 mm. diam. ..	22·59	43·38	5·66	12·69	16·45
Fine sand 0·2 to 0·04 mm. diam. ..	37·57	20·15	19·08	28·51	11·53
Silt 0·04 to 0·01 mm. diam. ..	17·77	7·88	38·82	24·79	13·66
Fine silt 0·01 to 0·002 mm. diam. ..	7·93	10·83	19·22	14·31	15·76
Clay below 0·002 mm. diam. ..	11·10	13·05	11·67	13·90	34·79
Calcium carbonate ..	0·31	0·20	0·08	0·04	1·18
Loss on ignition	2·42	4·47	3·58	3·19	5·02
Nitrogen	0·57	0·27	0·44	0·45	0·48

Except on silts recently deposited from the rivers, paddy is the only crop which can be grown on these soils. Pendleton describes how the sediments brought down by the rivers continue to extend the land southwards, besides periodically depositing finely grained alluvial materials over the area. The coarsest particles are deposited on the banks of the rivers, thus building up natural and fertile levees on which villages are established, the finer particles being deposited over the back country. It is because these soils have developed from very finely grained alluvial material, and because weathering has continued in the uppermost portions of these materials, that the soils of the plain are almost entirely clay. The floods deposit silt and clay from higher upstream, bringing plant material in addition to inert leached material.

The soils of the Central Plain of Thailand[209] are almost impermeable, being heavy clay overlying similar material. In some places crystals of gypsum are found near the surface. Thailand soils were reported on by Bruce[32] who described them as clay silts, the coarse particles being 8 per cent, silts 48 per cent, and clay 27 per cent.

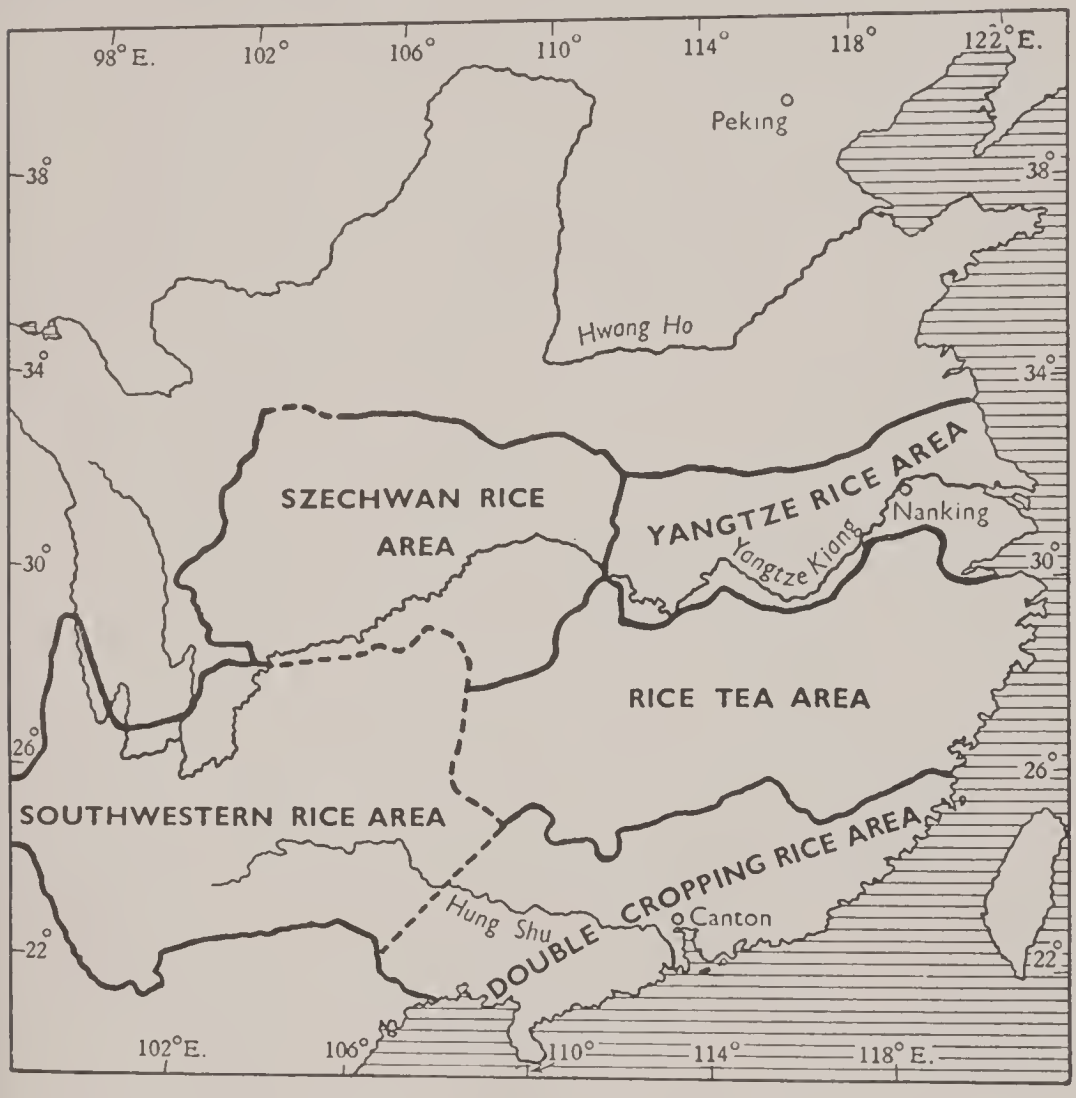


FIG. 1
The rice areas of China
(After J. L. Buck, *Land Utilization in China*)

Ladell has shown that the yield of paddy increases as the percentage of fine fractions ranged from 63·8 to 72 per cent. But in practice no reconnaissances to determine whether or not the soil is likely to be suitable for paddy cultivation are carried out in Thailand, water supply being held to be the dominant factor, so that light, rather sandy soils are considered suitable provided that sufficient water is available to compensate for their poor water-holding capacity.

The physical characteristics of Malayan paddy soils are 27 to 46 per cent of fine sand, while the fine fractions are approximately 40 per cent clay and fine silt, and 20 per cent of coarse silt. The best land in Malaya, producing exceptionally high crops, contains 21 per cent fine silt, 15 per cent silt, and 58 per cent of clay. Land in Kedah, immediately south of Thailand, showed on analysis 31·7 per cent of fine silt, 27·2 per cent silt, and 31 per cent of clay.[28]

Buck[33] has classified the paddy areas of China (see Fig. 1). He shows that the rice regions in that country lie between latitudes 23° and 32° north, and extend from sea-level to 1,500 metres. The climate in the rice region is temperate and sub-tropical considerably tempered by maritime influences along the coast. The humidity is high, and the average rainfall about 50 inches. The growing season is about 326 days, the average temperature being 67·1° F. The summers are very hot and humid, but in the winter frosts are experienced in some areas. In the northern half of the area winter crops, such as wheat and barley, are followed by paddy in the summer; in the southern half of the region there are no winter crops, therefore paddy is followed by paddy. Double cropping extends over two-thirds of the area. Thorp[252] states that in some places a small third paddy crop is obtained in the year by interplanting before the second crop is harvested. Buck's divisions of the Chinese area are —the double-cropping area of Kwang Tung 113° E. longitude, the South-western area 30° N. latitude, and the Yangtze area 116° E. longitude; south of this is the rice-tea area. Paddy is thus grown on a wide range of soils in China, varying in origin as also in composition. Thorp states that the highest yields are obtained from the dark-coloured, slightly podzolized or unpodzolized soils, but adds that good yields are also obtained from the podzolic types developed from the recent alluvium in the large valleys. There are also large areas of paddy soils in China that are but little podzolized, most of which are dark in colour and some almost black. They occur in the flood plains of the great rivers and lakes of Szechwan eastwards to the China Sea, and south-west along the sea-coast on the deltas of the various small rivers. These dark soils are characterized by the almost complete absence of sand, and the approximately equal amounts of clay and silt. The podzolized paddy soils developed from the Old Red Earths are very poor, but by continual cultivation and very heavy dressings of manure they are made to give surprisingly high yields of paddy. The red paddy soils developed from the grey-brown and brown podzolic soils or from alluvium in the small valleys between them are more fertile, and are able to retain fertilizers longer than the soils derived from lateritic materials.

Many of the paddy soils in the fertile Szechwan Basin are developed entirely from the purple-brown and purple soil materials washed down from the hills. Most of these soils derived from the purple-brown materials are slightly acid in reaction and are quite productive. The Old Red and Yellow Earths, though very poor, are made to produce high yields by heavy and continued manuring.

Thorp states that most of the soils on which paddy is grown in the Yangtze rice-wheat area are non-calcareous, heavy-textured, stiff and plastic, where drainage conditions are imperfect or poor. Good crops can, however, be produced on the friable, light-textured types of soil, provided there is a heavy substratum to hold up the water. Much of the paddy lands in China, as is pointed out by both Thorp and Buck, have been changed materially by cultivation and manuring until they have been adapted for paddy cultivation, regardless of their original characteristics, and Thorp states that practically all the alluvial lands have been renewed many times by periodical depositions during the past forty centuries.

Thorp has attempted to correlate types of paddy soils in China with yields obtained. His data shows that the highest yields are obtained from the grey-brown podzolic soils, the dark-coloured silty paddy soils, and the non-calcareous grey silty and clayey alluvium. The poorest yields are obtained from the podzolic grey-brown clay pan, many of the podzolic Red and Yellow Earths, and consistently from the calcareous alluvium.

"The use of night-soil as a manure and the cost of transporting it for more than a limited distance," observes Richardson,[217] "has led to the building up of a ring of highly fertile soils around the cities, with a corresponding degree of impoverishment of the country farther away. . . . In the hilly parts of China the fertility of the soil is generally lower than on the plains, crops are poorer, and the effects of nutrient deficiencies are evident to the eye." This heavy fertilization around cities has also been noted in India.

The soils of Formosa are mainly composed of sandstones and shales of a fairly light and free-draining nature and, at best, of moderate fertility. Owing to the rapid decay of vegetable matter and heavy leaching, they are poor in humus throughout the island. From the extreme north down to the western plain, to approximately mid-point, soils contain very little clay, are acid in reaction, and are lacking in plant food. South of the Tropic, the soils are more clayey, the proportion of clay reaching its maximum near Tainan and decreasing further south. Certain of the soils on the east derived from crystalling limestones and schists, with mixed sandstones and shales, are alkaline in reaction and poor in nitrogen.

In contrast with the heavy soils usually associated with paddy cultivation in Asia are the soils of the paddy-growing area of Italy, which are generically more or less sandy clays. In the Vercellese region of high yields the soil is described[250] as alluvio glacial types except in the neighbourhood of river-beds where they are replaced by recent alluvium. Luigi Boragia[146] gives the following four mechanical analyses of typical soils in this area.

TABLE 4

MECHANICAL ANALYSES OF ITALIAN PADDY SOILS
(percentage)

Description	*Soils*			
	1	2	3	4
Coarse earth about 1 mm. diam.	10	5	2·5	2·0
Fine earth below 1 mm. diam. ..	90	95	97·6	98·0

The chemical analyses of the first two of the above samples is stated to be:

	Percentage	
Moisture	1·40	1·34
Organic matter ..	3·40	2·90
Calcium carbonate ..	trace	trace
Phos. anhydride ..	0·02	0·02
Pot. oxide	0·009	0·015
Total nitrogen ..	0·19	0·15
Total phos. anhydride	0·17	0·12
Pot. oxide	0·11	0·11
Calcium oxide ..	0·49	0·65
Magnesium oxide ..	0·79	0·67
Acidity (pH) ..	6·6	6·8

The soil of the Murrumbidgee Irrigation Area in New South Wales is described as shallow, medium to heavy clay soil overlying a stiff clay subsoil which had previously proved unproductive when sown to other crops. This soil, under a rotational system yields an average of 1·8 tons of paddy per acre.[111]

In California[269] paddy is grown on a soil that is described as sticky and waxy. It holds water well, but cracks badly when thoroughly

dry. The grey to black soil of this type, known as Stockton clay adobe, is said to be typical of most of this paddy-growing area of California. In the Sacramento Valley the principal soils on which paddy is grown are the clays and clay adobes of the Stockton, Willows, Sacramento, Capay, and Yolo series. The mechanical analyses of these soil types are shown in the following table.

TABLE 5

MECHANICAL ANALYSES OF SOME CALIFORNIA PADDY SOILS
(percentage)

Soil	*Fine gravel*	*Coarse sand*	*Med. sand*	*Fine sand*	*Very fine sand*	*Silt*	*Clay*
Stockton clay adobe:							
Surface 0–28″ ..	0·2	0·4	0·9	3·5	16·7	32·2	46·0
Subsoil 28–40″	0·6	0·9	0·1	3·5	20·7	30·4	42·3
Substratum 40–70″	0·3	2·3	2·8	6·6	26·6	40·2	21·7
Sacramento clay:							
Surface 0–40″ ..	0·7	1·9	1·4	6·7	22·4	34·9	32·6
Subsoil	0·9	1·4	2·1	7·1	24·0	31·8	32·9

CONCLUSION

Provided that the water supply is adequate, paddy cultivation is possible on a wide range of soils, both light or heavy, although the crop favours a heavy soil with an acid reaction. Many unpromising soils may be built into good paddy-producing soils by cultivation and heavy manuring.

Chapter III

WATER SUPPLY AND CONTROL

Drainage and Irrigation—Water Requirements—Quality of Water—Water Control—Water Control between Seasons—Primitive Methods of Irrigation—Modern Irrigation—Empoldering—Irrigation in some Countries of Production—Economics of Irrigation Works—Cultural Regulations—Conclusions.

DRAINAGE AND IRRIGATION

THE successful cultivation of paddy depends on the adequate inundation of the fields during the greater part of the period of growth of the plant. This sounds simple enough, but in practice this desideratum is reached only after solving a number of problems that vary in importance in each particular case. In many areas it becomes not so much a matter of supplying sufficient water as to control the water; not always the supply of water but its drainage, or again, it may be the supply of water at one time of the year and its drainage at a later date.

Irrigation therefore implies not only an adequate and controlled water supply, but also efficient drainage of excess water whenever desirable.

The supply and control of water is the most important aspect of irrigated paddy cultivation; given an adequate and well-controlled water supply the crop will grow on a wide range of soils and of climate. It is, therefore, more important than the type of soil.

It is generally agreed that the paddy crop should be planted in a well-soaked field but with little standing water, and that the depth of water should be increased as the plants grow until the depth is from six to twelve inches. This applies to transplanted paddy; other conditions are necessary with broadcasted or drilled paddy. When the plant flowers the water should be gradually drawn off till at harvest time the field is dry. During the growth of the plant the water should never be stagnant, but gently flowing. It is important that the soil should be well aerated. This can, in part, be achieved by cultivation, but it is also attained by the movement of water over the area. Where the paddy field remains under stagnant water for any length

of time the growth of the crop is affected, probably due to the fact that decomposition of organic matter depends largely on oxygen and in the absence of oxygen nitrates cannot be formed. It is possible, too, that chemical reactions induced by anaerobic conditions lead to the formation of substances toxic to the paddy plant.

This simple statement of the water requirements of the crop may be open to question, for the optimum depth of water appears to vary in different countries. It is, however, generally accepted that adequate tillering is desirable with transplanted paddy, and except possibly in the cultivation of special varieties of paddy, deep water inhibits tillering and results in a decreased crop. Further, it cannot be disputed that the water should, if possible, be in a state of gentle movement and stagnation avoided. Necessarily, this is a counsel of perfection, for over the vast majority of paddy-fields in the East the cultivator has incomplete control over the water supply. Considering the difficulties, the degree of success achieved by the Asiatic cultivator in harnessing water for the irrigation of his fields must be recognized.

WATER REQUIREMENTS

The actual quantity of water required by the crop depends on a number of factors. An excessive quantity of water on the land will not influence transpiration of water by the plant for this remains constant regardless of the degree of saturation of the soil, although transpiration is increased by the application of phosphate, the effect being greater the drier the soil.[100] In India also[232] it has been found that manuring lowers the water requirements of the crop and that farmyard manure is more effective in this respect than artificials. The paddy plant, in fact, takes no more water than do dry-land crops, but evidence[243] suggests that swamp conditions provide constituents such as silica, which are not ordinarily readily available in the dry soil.

The principal factors influencing the consumption of water are field evaporation, seepage, preparation of land, and initial flooding; while the conditions that have an important effect on these factors are—climatic conditions, characteristics of the soil, length of irrigation period, ground water-table, yield and method of planting, as well as method of irrigation. Temperature, humidity, and wind velocity are the main factors affecting surface evaporation and transpiration in paddy-fields.

In Japan[139] the water requirement of the crop varies from 2·3 to 4·3 acre feet for the entire season, the standard depth of water in the

field being from one to two inches. This authority adds that immediately after transplanting the water should be rather deep to hold the seedlings upright, and should be shallow at the tillering stage. Fields are dried for weeding or for the application of a top dressing of fertilizer. The irrigation is delayed for several days after top-dressing to prevent the loss of fertilizer through leaching. The fields are finally drained when the crop begins to ripen. In many fields, however, this degree of control of water is impossible.

In Thailand it is considered that the total amount of water required by the crop is six feet, but in most parts of the central plain the quantity of rainfall normally received during the growing period from June to November falls short of this amount on an average of 2·5 feet, so that the aim of the Irrigation Department is to utilize the natural water resources to augment this deficiency in rainfall and to regulate the quantity of water admitted strictly in accordance with the requirements of the crop. It is stated that the ideal in this respect is to hold the depth of water in the field at about 30 per cent of the height of the growing plant.[34] In Indo-China it is considered that the amount of water required during the five months when the paddy is planted out is four acre feet, but this figure does not take into account the water required for the nurseries and for the preparation of the ground. In Ceylon, six acre feet are considered necessary for a dry-season crop of from three to four months.[145] The average amount of water used on the Murrumbidgee Irrigation Area of New South Wales is about six acre feet per season, the actual requirement being influenced by the underlying geological and hydrological conditions, the season, the density of the crop, and the layout of the field.[111]

Loss of water by evaporation can be very great under tropical conditions. Over a twelve-month period in Malaya[123] the loss amounted to 56·54 inches. Similar losses have been recorded from British Guiana.

In Louisiana and Texas[79] forty-eight to sixty inches of water are required to produce the crop; of this a quarter to one-half may be supplied by rainfall during the growing season, the remainder must be supplied from wells and streams. The actual requirements, however, vary according to the topography of the land, as the presence of natural sloughs or drainage courses passing through the area will drain off some of the irrigation water. In California, from sixty to seventy-two inches of water are said to be required. Poorly constructed bunds will increase water requirement through loss by seepage, and further, unskilled use of water supply results in waste of water.

QUALITY OF WATER

The yield of paddy depends in no small measure on the quality of water used for its irrigation. Water may have considerable fertilizing value due to mineral nutrients in it, or may cause damage to the crop by poisonous or indirectly harmful substances.

The quality of water is dependent on its origin. River water is generally preferable to that from other sources. In addition to the fertilizing elements dissolved in such water, it carries silt. While large masses of silt must be avoided, a reasonable quantity of coarse silt deposited on the land has a favourable physical effect on the soil. Very fine silt carried to the land in like manner frequently has an unfavourable effect on the plant's growth.

Den Berger's[286] experiments in Java showed that paddy-land distant from the source of irrigation water receives less water than those situated nearer the source of supply, and the silt content of the water also decreases quickly as the water flows over the land. The crop decreased markedly with the distance from the source of water supply, the difference in yield between fields irrigated with first-hand and second-hand water being very marked. It was concluded that the plants in the first field consumed a great part of the fertilizing substances in the water.

In controlled irrigation schemes, provided with separate drainage and irrigation canals, it may prove necessary in times of water shortage to pump water from drainage canals to replenish water in the irrigation canals. While such a course may be employed to keep the land inundated for a few days to tide over a water crisis, the general practice of using water more than once for irrigation must be deprecated, as it will be reflected in decreased yields of crop.

WATER CONTROL

Water control is essential if the growing crop is to be provided with adequate supplies as needed. It is customary in many countries to drain the land at least two or three times during the growth of the crop, usually in connection with weeding and fertilizing. Periodical drainage is not possible, however, if the water supply is uncertain, or its control imperfect, as inability to re-inundate the fields would endanger the growing crop. The yield is seriously affected if the supply is insufficient, especially at the time of "earing." Small quantities of water given at frequent intervals are more conducive to high yields than are larger quantities given at less frequent intervals.[209] In most countries, however, the irrigation periods are less

frequent. In Italy, for instance, the fields are dried twice during growth, first for four or five days about twenty-five days after sowing, and again after the last weeding the water is withheld for a few days. It is stated that this drying of the land has beneficial effect on soil aeration and root penetration. On the other hand, the custom of irrigating by day and draining by night is considered useless and often injurious.

WATER CONTROL BETWEEN PADDY SEASONS

Whether the land be flooded or retained in a dry condition between paddy seasons is a debatable subject. In many regions the cultivator has no choice in the matter; the crop is grown during the rainy season and there is no water available to flood the land in the off-season. In south-west China[109] the water fallow practice in winter on the paddy-fields is considered an important measure to store water for paddy cultivation in the coming spring and also to maintain soil fertility by the process of waterlogged weathering. It is suggested, however, that in this area the cultivation on paddy-fields during the winter of wheat instead of using the land to store water is to be recommended, provided that manures are available and that storage of water is not essential for the subsequent irrigation of the paddy.

The drying of the land in the off-season is generally considered beneficial, as the process releases some of the nitrogen and phosphorus tied up in the soil organic complex. In Japan[208] so important is this drying of the soil considered that in some areas where the practice is rendered impossible by reason of inadequate water control, soil is removed from the field, dried under shelter, and returned to the land a few days before transplanting commences.

PRIMITIVE METHODS OF IRRIGATION

Asiatic manipulation of water for paddy cultivation is almost always directed towards lifting water from natural supplies and directing streams over the area. Methods to conserve water are usually beyond their power or resources, so that almost invariably the cultivation depends upon the ability to utilize seasonal rainfall. It is for this reason that the vast and historic paddy-growing areas are in the wet tropics, or are adjacent to rivers that seasonally overflow their banks and inundate the surrounding country. The amount of rainfall considered necessary has therefore but local significance, depending as it does upon the nature of the country and the natural

facilities for maintaining flooded conditions sufficiently long to enable the crop to grow.

The development of irrigation works by governments achieves two objects; firstly, as applied to existing paddy-fields it relieves the grower of anxiety over seasonal variations of rainfall, and secondly, by making better use of the available water it enables an extension of paddy planting in areas that otherwise would be considered unsuited to the crop.

The two chief methods used by the cultivator for the raising of water for flooding his land are by damming streams, or by lifting water from rivers or wells by waterwheels or gear operated by hand or by oxen.

The building of a dam[92] is usually carried out on a communal basis; that is, cultivators whose land will benefit as a result of the dam assist in the work of construction. The banks of the river above and below the proposed dam are strengthened by wooden stakes and split bamboo. A row of very thick stakes is driven into the bed of the river from bank to bank. The distance between the stakes will depend upon the strength of the current and the depth of the river. Between these stakes, which may be three feet apart, are placed smaller stakes, but still of no mean size. Thus is formed a row of stout stakes from bank to bank of the river. At a distance of about two feet up-river from this row of stakes a second row is erected, parallel to the first, composed of wood of about two inches diameter.

Meanwhile, bundles of sticks tied with roots or rotan have been collected and brought to the site. These are placed at right angles to, and between the two rows of stakes. The bundles are about fifteen inches in diameter. In placing the bundles into position, care is taken that they are well pressed down, and the thick ends close up to the stronger line of stakes. This erection of bundles of wood is carried to the ultimate height of water over the dam. When this work is completed it is seen that a great quantity of water finds its way between the bundles, and the level of water above the dam is not materially altered. Sods of turf, earth and grass, freshly dug, are then packed behind the dam, till the level of this mass rises to the height of the dam. The water has now risen on the upstream side of the dam and flows into a watercourse which carries it to the paddy-fields. Surplus water flows over the dam. In cases where there is a considerable weight of water behind the dam, the dam is further strengthened by placing large poles diagonally from below the dam, the upper and forked ends of which support the large upright poles first erected.

Below the dam, at a distance from it of perhaps ten yards, a small fragile dam is made of a row of stakes against which are placed split bamboo. This is a very necessary precaution against the danger of the undermining of the dam.

It will be realized that the construction of a dam calls for great patience and much hard work. The resultant dam is frequently quite inadequate to withstand a strong flood such as frequently results from torrential tropical rain, and such a catastrophe may spell ruin to the growing crop by withdrawing water supply at a critical period.

The usual type of waterwheel is usually undershot and designed to lift water from a river for the irrigation of land on one bank, but occasionally land on both sides of the river is irrigated from a single wheel.

The diameter of the wheel is from twelve to fifteen feet and supplied with bamboo internodes from ten to fifteen in number for lifting the water. The hub of the wheel is of hard wood, affixed at either end to a wooden platform. The wheel cannot rise and fall according to the height of the river. The spikes are of bamboo, and the circumference of the wheel constructed of twisted rotan. The water when lifted falls into a wooden trough which delivers it to the watercourse serving the paddy-field. The amount of water lifted is usually sufficient for about three acres of land.

In the vast areas of Lower Burma, from which the bulk of the exportable crop of that country comes, real swamp conditions exist and there appears to be little or no control of the water supply. Further up-country irrigation is practised, while small areas also exist, bordering rivers and subject to flood where successive plantings are possible, level by level, as the flood water subsides.

Mention must also be made of the terracing of mountain-sides for paddy cultivation which may be seen in various parts of Asia, particularly the Ifugao terraces in northern Luzon in the Philippines, and in parts of Java and Ceylon. The Ifugao terraces cover an area of about 250 square miles and is a remarkable piece of engineering, even judged by modern standards. Terraces of this description are irregular, conforming to the configuration of the land, and must have entailed a tremendous amount of work in construction. The water is obtained from mountain streams, irrigation channels being made so that the whole area is supplied. Great ingenuity is shown in the employment of the water, which sometimes has to be carried over chasms.

The Asiatic has shown considerable skill in the methods employed in the harnessing of water for the irrigation of his paddy-land. Levels have to be worked out by eye on a trial-and-error basis—and the

errors are few. The main weakness of the work is usually its impermanence, for most of the dams, waterwheels, waterways, and other devices he constructs last but one season, while heavy rain may destroy his work soon after its completion. The employment of such methods usually restricts cultivation to areas of heavy rainfall, or to natural undrained swamps. Paddy cultivation, however, does not depend on heavy rainfall, but on adequate irrigation, and where this is possible by the construction of modern irrigation works on a large scale the cultivation of the crop may be extended to areas of lower rainfall.

The Persian waterwheel and the Shadouf are two ancient and primitive methods of lifting water for irrigation, still in common use in the Middle East and India. Tothill[262] describes the former as a large wooden wheel with wooden teeth on the outer rim, mounted on a vertical wooden shaft, from the upper part of which projects a horizontal arm to which are yoked two bulls. This wheel drives a similar but smaller wooden-toothed wheel, mounted on a horizontal shaft, the other end of which carries a large open-spoked wheel with a wide periphery. The latter carries two parallel endless ropes, joined by spacing bars, to which are attached a series of water containers. The loop of the parallel ropes dips into the water, and as the wheel revolves, the filled containers are carried to the top of the wheel, where they spill their contents into a trough, whence the water flows to the field. This waterwheel can raise water three to eight metres, but is considered an inefficient method of lifting water.

Tothill describes the Shadouf as a very primitive but effective and cheap method of raising water by man-power through two or three metres, with the added advantage of being easy to construct and maintain. It consists essentially of two posts supported by a cross-bar on which is pivoted a long wooden lever, to the shorter end of which is fixed a weight to act as a counterpoise to a rod or rope and dipper attached to the long arm. The rod is seized high up and pulled down until the dipper enters the water. The full dipper is then allowed to rise, pulled up by the counter-weight, until it reaches the level of a trough or channel into which it empties, the water flowing to the field. At a lift of two metres it is stated to lift from three to five cubic metres of water per hour.

A common method of raising water, practised in China, is by means of a locally made foot-pedal machine, light enough to be carried by one man from one terrace to another. It is described by Efferson[76] as being built of wood, bamboo, and paddy-straw rope. He states that it is composed of a long, narrow wood trough from twenty to forty feet in length, about a foot wide and a foot deep.

Moving up this trough is part of a wood and paddy-straw circular chain with paddles about every foot that fit into the trough. The circular chain is attached to a roller on the upper end by means of wood gears, and on the roller there are several footrests, similar to the spokes of a wheel. The power, when applied to these footrests, turns the roller, which in turn moves the circular chain up the trough, pulling the water from the lower terrace or stream up to the field being irrigated. The power is human, the worker treading the footrests with a movement similar to that used when riding a bicycle. The more typical machines have positions for two people, and on large farms there may be four and sometimes six people operating one of the larger machines. A more elaborate wooden-gear attachment is sometimes used so that the power may be supplied by buffalo; these outfits, however, are not movable and are used only for the first lift from the stream to the lowest terraces of the field.

In contrast to the above, and perhaps indicating a sign of the times, the writer has seen a Tangye pump, owned by a small cultivator in British Guiana and let on hire to neighbours, for pumping excess water from paddy-fields.

MODERN IRRIGATION

Irrigation schemes may have any of the following objects in view: firstly, the replacement of the native means of raising water by modern and permanent works, such as dams; secondly, the construction of permanent works for the irrigation of new areas, by such means as the empounding of water in reservoirs, pumping schemes, and dams; and thirdly, by devising drainage schemes. Drainage is often more important than irrigation, and many existing areas have been improved by the adoption of schemes to drain the land as required.

While the paddy plant is tolerant of considerable variations in the quality of water in which it will grow, there is no doubt that to produce the best results the plant should be supplied with water which carries no contamination. An excessive quantity of silt is inimical to the plant, and very careful precautions are sometimes necessary to prevent damage on this account. One would expect that well-aerated water is best, but this is not always possible to obtain. Water in movement will ensure a degree of aeration. Temperature of the water may have an effect on paddy growth, but of this there appears to be no direct evidence. The writer has often observed that the growth and tillering of paddy is more vigorous at the head of valleys

that receive very cold water newly emerged from the mountain stream than it is downstream, but this improved growth may well be due to fertilizing material dissolved in the water or to aeration of the water.

It has been pointed out that the primary work of a drainage and irrigation department is the provision of permanent works to replace the temporary works constructed by the cultivators. As a result of native methods the land is not irrigated to its greatest advantage. Permanent works may be expected to result in better controlled water systems with fewer dams and with less work on maintenance. "Irrigation practice," states Murray,[168] "concerns itself with the elevation of river flows to riparian areas by means of dams or pumping plants. The usual system of feeder channels is provided on a pattern to suit local conditions, and a comprehensive system of drainage to remove excess water from unseasonal rainfall is an essential feature. . . . In addition, certain areas which have no available supply of irrigation water are operated as controlled drainage areas in which the water-table is carefully controlled by drainage works, and rainfall in the area is retained or drained off as circumstances demand. Areas of this type are found in the flat coastal belt [of Malaya] and in small tributary valleys adjacent to the large rivers." Murray continues by pointing out that irrigation practice aims at the supply adequate to the growth of a long-term paddy with an eight-months' maturation period, as this gives the heaviest yield and consequently the best return for the capital outlay. With this view the present writer is in complete agreement as he holds that however good the water control may be, maximum yields cannot be expected with short-duration crops. Murray instances that during the Japanese occupation of Malaya they introduced a variety of paddy from Formosa capable of producing two crops a year, but that there was no evidence that the two crops produced in the aggregate more than one long-term crop. This bears out the present writer's experience with Japanese short-term varieties. It is therefore imperative that irrigation systems should be devised on the assumption that the water is required for a long-term variety, which means that usually only one crop is to be harvested a year. In regions where winter conditions obtain, the summer variety must be of shorter duration and irrigation facilities may be required for only about six months in the year.

The prerequisite of efficient and economic paddy production is adequate control of the drainage and irrigation throughout the season. During this period the water should be available for each field as soon as it is sown. A drainage and irrigation system cannot,

however, be based on average conditions, it must be designed to supply adequate water during seasonal shortage and to drain sufficiently rapidly in periods of excessive rain. Where this entails the provision of reservoirs it may not always be possible, or where possible, the capital expenditure may not be justified by the area of land which may be expected to benefit by the improvement. In tropical areas reservoir sites should be deep in relation to surface area because of the large evaporation that may be expected.

The great objection to native-made dams is that they often result in serious breaking down of the banks of the rivers and in silting up of rivers. Furthermore, they make provision for raising the level of the water to irrigate the fields, but make no provision for draining water during periods of heavy rain. For this reason they often cause sweeping torrents of water to flow over the fields, doing great damage to the crop. The concrete dams constructed by irrigation engineers are provided with gates so that this sudden flow of excess water may be rapidly drained off. The action serves also to flush out the river and thus maintain the depth of the bed.

EMPOLDERING

Empoldering is a method of restricting floods and thus securing adjacent areas from submergence. The Dutch are probably responsible for introducing this system into British Guiana in the eighteenth century. To-day, all the land developed for paddy cultivation in this colony and in the adjacent Dutch colony of Surinam is protected by this means.

A tract of swamp land is completely surrounded by a dam and dyke, thus denying to the enclosed area unrestricted quantities of water from land outside the protected area. Through the centre of the empoldered area an irrigation canal is constructed, in which the water is controlled by suitable sluices. Drainage canals are made on two sides, parallel with the irrigation canal, the water in the drainage canals being kept at a lower level to that of the irrigation canal. Thus, by using the slight difference in level towards the sea, or the difference in level between high and low tide, the amount of water within the polder is controlled. In the absence of sufficient fall, pumps are installed to give adequate water control.

The system, if extensively developed, is liable to lead to grave trouble, due to the enforced restriction of flood water, resulting in occasional breaking of the dams and consequent widespread flooding as a result of abnormally high rainfall.

IRRIGATION IN SOME COUNTRIES OF PRODUCTION

From early times tanks were constructed and used in Ceylon to store water from rain and rivers in the wet season so as to ensure the water supply for the paddy season. The Irrigation Department has restored or improved many of these ancient works which now adequately serve a considerable area. The Department has also developed irrigation from rivers whereby water is led from a river through a channel as a result of a masonry anicut constructed across the river. Further schemes of this nature are under consideration which will probably irrigate some 200,000 acres. Other more primitive systems of irrigation practised in Ceylon include basin irrigation, whereby a temporary dam is placed across a small stream, resulting in the raising of water in the stream above the dam till it overflows its banks and floods the surrounding country; lift irrigation, a primitive method practised in the dry district of the Jaffna peninsula, whereby the water is lifted from wells usually by a well sweep; and collection by direct rainfall only, or by rainfall supplemented by run-off from neighbouring higher land, a method satisfactory only in the wetter regions of the island.[184]

In Lower Burma, empoldering is used as a protection in some regions against floods, and canals for drainage. One of the oldest, constructed in 1880, protects 140,000 acres; the Irrawaddy Embankment, completed the following year, protects 630,000 acres. In Upper Burma, improved irrigation dates from 1890; major works include the Mandalay Canal controlling 90,000 acres, completed about 1902, the Shwebo Canal constructed about four years later and irrigating 29,000 acres, the Mû Canal in 1911 serving 70,000 acres, and the Ye-u Canal completed in 1918 and irrigating 90,000 acres.

In 1920 two million additional acres of the sea-coast were made available for paddy, but these low-lying areas are only cultivated efficiently when prices are high.

Analyses of water from deep wells in the Shiga, Chiba, Nagano, Nigata, Fukui, and Shimane Prefectures of Japan and in all oil-producing districts of Japan show that water from some of the wells contains from thirty to fifty parts per million of nitrogen as ammonia. In Nagano Prefecture near Lake Suwa, a private company is supplying neighbouring farms with ammonia-rich well water, while farmers in Shimane Prefecture are using similar water from wells to irrigate paddy-fields.[208]

In Thailand[34] there are a number of irrigation schemes in operation and projected, which if or when completed will embrace the

whole of the Central Plain. In the meantime, the crop is still largely dependent on the vagaries of rainfall, and the existing irrigation schemes cannot supply water irrespective of the rainfall on the Plain.

The general trend of the rivers of the Central Plain is north–east, and they are intersected by a series of canals. At appropriate intervals there are sluice gates, usually of the undershot type, by means of which the level of the water in the canals can be regulated. During the off-season, when there is little rainfall, the control gates are kept closed with the object of maintaining the water level as high as possible in the canals, thus keeping up the water-table in the fields, so that, with the advent of the monsoon rains, the soil quickly becomes saturated and the water-table reaches the surface. As the rains continue and the water in the canal rises, water can, if required, be forced into the fields to supplement the rainfall. If, on the other hand, the depth of water in the fields becomes excessive, the sluice gates are opened and water is drained off the fields. The canals thus function as irrigation canals or as drains as required.

The water supply and control appear to depend on the height to which the rivers of the Plain, the Memem Chao Phya River in particular, rise and inundate the fields. The rise depends on the amount of rain in the mountains where the rivers have their source. The rise should not be too early or the crop may not be sufficiently well grown to withstand inundation, nor too deep as to inhibit tillering or damage the crop. If the inundation is delayed the crop may be too far advanced to take full advantage of the water. An exceedingly late flooding may affect flowering or interfere with the harvest. It is therefore evident that there are considerable variations from year to year in water supply and also of date when inundation may be expected. These variations result in great uncertainty from year to year of the supply of rice that may be expected.

There is some attempt in Thailand to supplement the early rainfall by pumping water from the canals, the endless chain being used and often operated by wind power. Although the quantity of water lifted is not great, it is often of great assistance to the nurseries in the areas where transplanting is practised. There are, however, no large pumping schemes in operation.

Where irrigation schemes exist, the construction of minor canals to lead the water to specific lots is left to the cultivator, the irrigation authorities indicating the most suitable alignment. It is understood that the cultivators co-operate with the Irrigation Department in this matter.

The levels of the Plain change so gradually that there is very little bunding required in the fields—an advantage, for it not only saves

10. A brushwood dam, Malaya

11. A new dam to replace a brushwood dam, Malaya

12. Watering fields from a stream

13. An Asiatic primitive water-wheel

time and renders cultivation easier, but it tends to reduce damage to the crop by rodents and to reduce the incidence of weeds.

In northern Thailand, streams of clear water are plentiful and the catchment area of the border mountains is enormous. This plentiful supply enables two crops of paddy to be raised annually. Basin irrigation is largely practised, much of the work being done by the cultivators under the leadership of their headmen. In the north-east region lack of water is more marked and the soils are light and non-retentive of water. The streams have small catchment areas and may cease to flow in the dry season, a fact which makes irrigation schemes somewhat difficult to devise. The rainfall in southern Thailand is about 100 inches a year, supplying ample water for irrigating the crop, despite the fact that the soil is light and unretentive.

In French Indo-China the need of irrigation facilities is reported to be greatest in the Tonkin Delta plain, where the density of population is high, the size of the individual holding small, and where an appreciable proportion of the area is made to yield two crops of paddy a year. Irrigation is at present available on about 600,000 acres of the total area of nearly two million acres planted with paddy. About 25,000 acres are supplied by pumped water and the remainder by gravitation with water impounded by dams. The earthworks to protect the low-lying areas along the Rouge Fleuve were first put in hand some seven hundred years ago by Annamites, and have now been improved and extended. Lowlands adjacent to the sea are protected from sea-water inundation by bunds. In areas where the crop is timed to be harvested in May the superabundance of water derived from rainfall or by inundation by the rivers is removed as quickly as possible to allow transplanting to be completed as early as possible before the dry weather sets in.

In Annam there are about 222,000 acres irrigated, mostly by dams on the rivers. In northern Annam on the Tonkin border, where double cropping is carried out, a number of irrigation works have been installed by private enterprise. In Cambodia the call for the provision of irrigation is less urgent. There are already public irrigation works in the area in addition to works constructed by private enterprise, often in the form of pumps to lift the water either into or out of the fields according to the needs of the crop.

The principal paddy areas of Cambodia are located near the Cochin-China border. This area and an extensive one along the Mekong comprise the floating rice regions. The key factor in the water supply is not so much the actual rainfall in the regions but the utilization of the inundation water when the actual rise of the Mekong occurs. The level of the water in the river commences to

rise towards the end of June, the height of the inundation takes place during late September after which the fall is relatively rapid. The annual depth of inundation is remarkably consistent, being about six feet, and in this connection the Great Lake appears to function as a sort of gigantic regulator.

In the adequately watered Mekong-Brassac delta in Cochin-China the problem is more one of drainage than of irrigation in existing areas, together with the reclamation of swamps. The rainfall is normally sufficient to raise a satisfactory crop. The plain is traversed by a network of large canals which run more or less at right angles to the flow of the several channels of the Mekong. Secondary canals interlink with the main canals and there are numerous tertiary canals, many of which are communally or privately constructed. The general layout resembles that of the Meman Phya in Thailand and the method of operation also appears to be similar, namely, the rise and fall of the tides, between which there is a difference of 0·5 to 2 metres, is utilized in order to hold up or drain off water according to the requirements of the crop.

Most of the paddy-growing region of Burma has an annual rainfall of from 100 to 250 inches, all of which falls during the five-month growing season. Consequently, little formal irrigation is practised.[76] The extent to which the Burma crop is rain-fed, states Binns,[114] may be gauged from the fact that only about 10 per cent of the 12·6 million acres under paddy just before World War II was classed as irrigated. About one million acres of this was irrigated from government sources in the dry zone. Of the rest, about half was under supplementary irrigation in the wet zones.

In Java and Madura[83] the cultivation of paddy dates from very early times. The rapidly increasing population in the nineteenth century, however, led to difficulties in meeting the demand under the somewhat precarious native irrigation systems. In the season 1848–9 famine, causing the death of about 200,000 people, resulted from the crop failure. In consequence, the government built in the plain of Demak a dam on the Tuntong River, simultaneously constructing the western and eastern irrigation canals, thus controlling the irrigation over some 30,000 acres. Following a further famine in 1872, the government undertook a complete technical irrigation of the whole plain.

In 1871 a committee was formed which investigated the possibilities of technical irrigation in several regions in Java. In 1885 a special service was formed charged with the complete project of irrigating all land considered suitable for the cultivation of paddy. Four years later this work was decentralized.

The most important irrigation works in Java have been constructed during the present century, and especially since 1916 the government has spent much money on such projects. The total area controlled by irrigation schemes by 1940 was over $3\frac{1}{4}$ million acres.

Government intervention in irrigation is considered desirable when large areas in flat country have to be irrigated, or when the native irrigation causes crop failure or excessive damage. Consequently, such irrigation systems are mainly in the northern coastal regions, and in the plains of mid and east Java; less water is usually available in these regions than elsewhere and the dry east monsoon is protracted.

Over 180 million guilders have been spent in the construction of irrigation works, or about 94 guilders per acre. Naturally, the costs vary; the well-known Pemali works, for instance, cost 48 guilders per acre, whereas the Krawang project cost about 203 guilders per acre.

In Egypt[277,71] the cultivation of paddy depends entirely on artificial irrigation from the Nile. There are two systems of irrigation; in the older system the land is divided into basins which are flooded during the annual rise of the Nile, the water so obtained being known as *Nili* water. The basins are surrounded with embankments to hold the water in the basin as the Nile falls, from thirty to forty days, the crop being sown on the sediment deposited with no further water and little tillage. It follows that only one crop, and that of short duration, can be planted, the fields being fallowed after removal of the crop until the following year.

The second and more modern method of irrigation from the Nile aims to regulate the distribution of water and to store a portion of the water from the Nile for the summer irrigation. This is therefore a perennial irrigation and the water so obtained is known as *Seifi* water. Under this system a chain of public canals totalling over eleven thousand miles carries water throughout the whole year to the fields, giving to each a fixed share by means of outlet culverts placed at the mouth of the private ditches of the cultivators. It is therefore possible to obtain two crops a year—not necessarily both rice. Drainage as well as irrigation is necessary with the perennial irrigation system because the high water-table is detrimental to the growth of the plant roots. Public drains for this purpose total some 7,700 miles.

Under controlled modern irrigation in Egypt paddy is planted frequently with the main purpose of washing the land of alkalinity, and doubtless on this account has developed a technique of water manipulation which not only serves the purpose of cleansing the

land but is particularly beneficial to the paddy. The land is flooded for cultivation purposes, smoothed down, and the germinated seed planted. It is then left for ten or twelve days in cold weather and for five or six days in warm weather after which the water is drained off, leaving the plants well established. The drawing off of the water is done in the evening, and should the weather be hot water must again be run on the land as soon as possible next day. The water then remains on the land for four days; this operation is repeated every four days for a period of one month. Thereafter the water is drained off and replenished every eight days for about a month. The drain and canal are then left open together so that the water is flowing in and out of the fields at the same time. After this, the water is changed every eight days till harvest time. The technique of irrigation varies somewhat according to the variety of paddy under cultivation. The above refers to Sultani; with the varieties Yamani and Subieri the land is left for two or three days after drawing off the water before again inundating. With Yamani the land may be allowed to become dry enough to walk on before irrigating again.

Paddy cultivation in Italy depends entirely on irrigation, some of the canals used for this purpose dating back to the fifteenth century. All these irrigation works draw water from the River Po or its tributaries by means of barrages erected across the water course. The most famous of these canals, the Canal Cavour, was opened in 1866; it takes its origin from the Po at Chivasso, where an elaborate barrage has been constructed. The canal is fifty-three miles long and has a maximum capacity of over 3,500 cubic feet per second. A number of hydraulic elevators and electric power stations have been established, the largest of which elevates the water of the river to a height of 175 feet, when it is delivered into irrigation channels.[250]

The main paddy areas in the United States[79] are situated in the states of Louisiana, Texas, Arkansas, and California. The irrigation water for Louisiana and Texas is obtained by powerful pumps from the sluggish streams that flow through the prairies to the Gulf of Mexico, and also by pumping water from deep wells. The provision of water for the areas is usually undertaken by private companies, who sell the water to the growers at from $8 to $10 per acre each season. This service includes not only the provision of the water but the construction and maintenance of the canals which carry it to the fields.

In Arkansas most of the irrigation water is carried from wells that may be anything from twenty-five to sixty feet deep. The size of the pump necessarily depends on the depth of the well and the acreage to be irrigated, but usually the pump will be designed to supply up

to five or six gallons of water per minute per acre. The cost of pumping is usually about $8 to $10 per acre.

For the irrigation of the interior valleys of California the water is obtained chiefly from the Sacramento and Feather Rivers by gravity and by pumps. Here, too, the provision of water for irrigation is in the hands of private companies, who sell the water on an acre-foot basis or at an annual charge per acre. Basing the water rate on volume rather than at a flat rate per acre tends to conserve water and to confine paddy growing to the heavier types of soil where the quantity of irrigated water required may be expected to be less than on the lighter types of soil as there is less loss of water by seepage.

Deep wells are not often employed in the Sacramento Valley, but in the San Joaquin Valley they are often the only supply of water. The official opinion is expressed that deep wells are expensive to dig, equip, and operate, and should not be depended upon for paddy cultivation unless they have been thoroughly tested before the paddy cultivation is undertaken.

The water flows by gravity through canals from the pumping unit to the paddy-fields where it is distributed to the crop through shallow irrigation ditches which run along the higher side of the field. The water is then applied to the fields through control gates, as required. At convenient places in the bunds irrigation boxes are installed. They are placed deep enough so that the bottom boards will not hold water back when the fields are to be drained. The depth of water is controlled by shutters which are placed in a vertical position across the opening of the irrigation box. By taking out or placing into position a narrow board shutter, the water can be lowered or raised as desired. Copeland[51] recommends the box-gate and describes it as follows: ". . . a box, open on top except as may be desired by the flash-boards on the upper side. A sill, about 6 inches deep, keeps water from eating under it, and the ends are similarly carried out and embedded. Forty-two inches wide and 14 inches deep is a convenient size of opening. For control of the water each gate is provided with one 6-inch, one 4-inch, one 2-inch, and two 1-inch flash-boards. The bottom of the opening of the gate should be in the plane of the ground surface, never any higher. The gate should be placed where it will drain the check thoroughly; very large checks require several gates in each dyke."

It will be realized that irrigation methods in the United States aim not only at the supply of adequate water, but at effective water control at all times, from the initial preparation of the land up to harvest. By this means not only is the crop assured of an adequate supply of water when required, but the system provides for control

over the drainage of the land. Without the provision of control of drainage and irrigation, the systems of mechanized cultivation in the form it exists in America would not be possible.

The manipulation of the water for the cultivation of paddy under the American mechanized cultivation system is detailed in Chapter X. Under this system the importance of good drainage is emphasized by American writers, who point out that "poorly drained land is usually expensive to cultivate, difficult to obtain good stands on, and seldom produces maximum yields. . . . Harvesting is usually more expensive on poorly drained than on well-drained land, and there is often a loss due to over ripeness which results in shattering."[79] The same authority points out that before the paddy is sown or irrigated adequate drainage for the low places should be effected, so that it can be well drained during the flooding season and before harvest.

ECONOMICS OF IRRIGATION WORKS

Governments are frequently concerned with the high cost of irrigation systems for paddy cultivation and the small return that may be expected on capital investment. This is inevitable, for one is dealing with a crop which has a low market value in comparison with most other crops. In their development of the rice industry in Java the Dutch took a most realistic view of this problem. To judge as to whether a system of irrigation would be justified, data was first gathered on the agricultural and economic conditions of the region and also on the probable profit from the project, the quality of the water, and on other agricultural aspects. A financial estimate was based on these data. Irrigation works were usually only undertaken when they were at least 50 per cent "fiscal remunerative"; in other words, the interest on the invested capital had to be at least 50 per cent of the rate determined beforehand. Thus, if the project yielded an interest of 3·6 per cent, and the determined normal rate of interest was 6 per cent, the scheme was considered 60 per cent "fiscal remunerative." Consideration was given in this way to the indirect advantages of a scheme of a social nature.[83]

The Dutch are now engaged on drawing up plans and have commenced operation on the development and settlement of an extensive area in Surinam (Dutch Guiana). Financial considerations appear to be on similar lines to those that guided their development of paddy cultivation in Java.

CULTURAL REGULATIONS

Cultural regulations are in many countries enforced to minimize damage to the crop by pests. The more general application of regula-

tions, however, is to ensure a fair distribution of water in areas where supplies are limited or where several parties are interested in the water distribution. Such regulations may take the form of limiting the total amount of water used, of prescribing the dates of planting so that only part of the total area requires water at the same time, or of limiting the total area planted with the crop annually. In most countries where such regulations are necessary, the control is usually entrusted to committees or water boards on which representatives of interested parties sit. A fully representative water board, supported by the necessary legislative authority, can usually arrive at a working arrangement which will ensure a fair distribution of available water supply.

In 1936 the Netherlands East Indies Government promulgated the General Irrigation Act, designed to utilize available irrigation water as efficiently as possible, and to prevent waste of water. Under this Act, the date is prescribed on which east and west monsoon irrigation is to start for each irrigation area separately. These dates may differ for each year, depending on the rainfall and the discharges of the rivers concerned. A culture project for the east monsoon planting within an irrigation region will concern rice, sugar cane, and secondary crops. After fixing the area of each, water is allocated in definite proportion for every region. The water is thus distributed in such a way that every crop should have an equal chance of yielding a good crop.

CONCLUSIONS

A comprehensive account of the irrigation of all the paddy areas is beyond the scope of this book. Instances have been given illustrative of the methods used. Each country has its own problems of irrigation and no generalized statement is therefore possible. One can but urge again that irrigation and drainage are the most important conditions in paddy cultivation, and that money expended on improvements in this direction may usually be expected to result in markedly improved yields. Such improvements, however, are likely to prove expensive, and there is little likelihood of the capital cost being available from the cultivators. In Asia these improvements are usually undertaken by governments. Many such improvements have been effected in the East, and the cultivators called upon to share capital cost with government, and to meet upkeep charges, by means of a water rate. Serious objection to such a charge is not to be expected, for the cultivators appreciate the fact that they obtain higher yields as a result of improved irrigation and drainage.

Irrigation for paddy cultivation is a problem for the engineer, but

paddy cultivation must be thoroughly understood in all its local aspects before embarkation on a project. Close collaboration between the agricultural expert and the engineer is therefore indicated, and it will usually be found advantageous to consult closely with the cultivators themselves, so that their needs are understood and so that the latter may appreciate the significance of projects that affect their livelihood.

Chapter IV

CHARACTERISTICS OF THE PLANT

Root—Stem—Leaf—Inflorescence—Germination—Environment—Water Requirement—Height of Plant—Tillering—Lodging—Maturation Period—Sterility.

Oryza sativa is a cultivated genus of *Oryza* Linn. of the Natural Order Gramineae, widely grown in tropical and sub-tropical regions, either as a dry-land crop or more usually in water for the ripe seed, which is the staple food in many Eastern countries. It is not, however, an aquatic plant, for the roots of aquatics produce but few branches and no root-hairs, whereas the roots of the rice plant—whether grown as a dry-land crop or in water—are much branched and possess a profusion of root-hairs.

The term "paddy" is variously applied to the land on which the plant is grown, to the husked or unhusked seed, to the cooked or uncooked grain. In countries where this cereal forms an important part of the diet, the vocabulary is particularly rich in words descriptive of every stage in the cultivation of the crop and its preparation as a food. As is to be expected, the importance of rice in commerce has led to numerous terms descriptive of various grades of the product as sold in world markets. This multiplicity of terms is apt to be extremely confusing. In the following pages an effort has been made to limit the use of such terms to a minimum; the two main terms used throughout are—paddy, the growing plant or the unhusked grain, and rice, which is the husked grain. Any deviations in the text from these two descriptions are appropriately explained.

Both wild and cultivated forms of *Oryza* are annuals, although it is said that at least one variety of wild paddy in Ceylon is perennial. The maturation period, as will be seen later, varies considerably in cultivated forms from two to three months up to nine months.

THE ROOT

On germination, a primary root develops from the base of the grain, quickly followed by two additional roots, all subsequently giving rise to short lateral roots. The main rooting system of the

plant, however, develops from the nodes of the stem below ground level. In the "floating rices," whorls of adventitious roots are formed from the first three very short nodes, giving rise to whorls of perma-

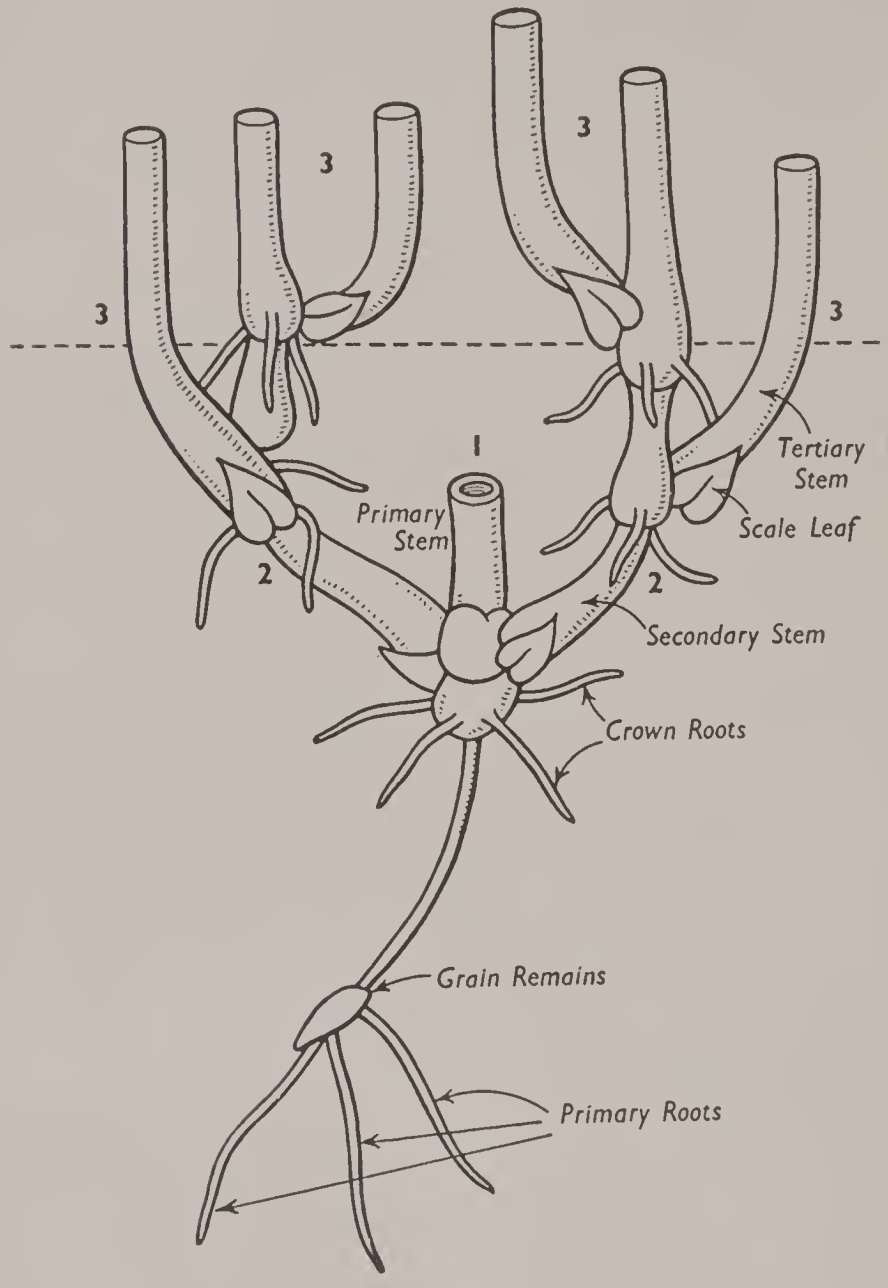


FIG. 2
Diagrammatic representation of tillering in cereals
(After Schindler)

nent adventitious roots. Tillers are produced at the nodes and further adventitious roots are produced from the lower nodes of these culms, so that the plant quickly develops a mass of adventitious roots. Under normal conditions the root system is fairly compact, the roots

tending to develop horizontally rather than vertically; the plant, therefore, draws its nutrients from near the surface of the soil. Root development is influenced by soil texture, cultivation, water and air in the soil, the amount of available food supply, and by the system of transplanting.

Sethi[231] states that after a fortnight's growth two distinct types of root are evident; long, flaccid, light brown and much-branched roots, and comparatively short, thicker, unbranched roots with a white waxy appearance. About six weeks after sowing, the white roots begin to branch and become weak and flaccid. These white roots increase in number from the fifteenth day till the appearance of the flowers. At maturity all roots are thin, branched, and flaccid. As the plant develops the older roots die, their function being assumed by the younger roots, so that towards the period of maturity, when few new roots are formed, the plant possesses a mass of living and dead roots until the plant reaches maturity, when most of the roots are dead.

Sato[229] observes that the number of roots increases gradually from the early period of growth towards tillering and shooting period, reaches the maximum at the heading time, and decreases gradually until harvest time. The ratio of weight of root to weight of top gradually decreases towards the shooting or heading time.

*Anatomy of the Root.** The young root has an epidermis of thin-walled cells which towards the apex grow out to form the root-hairs. Beneath the epidermis and separated therefore by a single layer of thin-walled cells is a single-layered exodermis of thick-walled cells. The remainder of the cortex consists of large thin-walled cells, the innermost constituting the endodermis.

The central cylinder is at first unlignified and at an early stage develops a number of very large central vessels—either a single central vessel or six vessels arranged starwise. To the exterior, groups of smaller vessels alternating with phloem and separated by thin-walled parenchyma, form a vascular ring. The xylem of these groups abuts on a single layered percycle. The remainder of the cylinder is constituted of thin-walled parenchyma.

As the root ages, the epidermis of the layer immediately beneath are sloughed and the exodermis replaces them. This layer then thickens further and its outer walls become subderized. Thickening of certain of the adjacent layers of the cortex may follow. Simultaneously, the radially arranged intermediate cells of the cortex separate from one another and alternate strands or groups of strands so formed may shrivel

* The following information on roots, stem, and leaf is drawn largely from *Introduction to the Botany of Field Crops*, Vol. I, Cereals, by J. M. Hector (South Africa Agric. Series, Vol. XVI).

and die. There is thus formed a cortical structure strongly resembling that of many water plants. Adjacent to the epidermis, which gradually thickens, two or three layers of cortical cells tend to remain more or less unaltered. At maturity the central cylinder is thus invested by a loosely pleated jacket-like cortex. The central cylinder also becomes modified. The vessels become lignified and in time the cells of the parenchyma are strongly thickened, thus forming a solid central core of the root.

The above statement is of importance as explaining the adaptation of the roots of the typically dry-land paddy plant to aquatic conditions.

THE STEM

The main axis of the stem is differentiated from the growing point of the embryo, enclosed at first by the coleoptile. The ultimate height of the stem depends on the number of internodes and on environmental conditions. Early strains of short maturation period have fewer internodes than have those with a long maturation period, but there are exceptions to this rule. The number of internodes may vary from about ten to twenty.

In the early stages of growth there is little difference in height of varieties; later, elongation commences and is continuous, reaching its maximum at flowering. Varieties of short maturation grow more rapidly than those of long duration. Internodal length tends to increase from the base upward. The terminal internode—the peduncle—carries the panicle and is the longest internode.

The culm is more or less erect, cylindrical, and hollow except at the nodes, and varies in thickness from about six to eight millimetres. Nodes are clearly defined by the presence of a distinct thickening, the pulvinus, immediately above the node. The pulvinus may be coloured, varying in intensity from a "touch" of purple to a deep uniform purple. The colour of the pulvinus is always associated with colour in the leaf sheath, but the converse is not found. The internodes may be green or coloured. The pigment in the coloured forms may be diffused in the epidermis or in the parenchyma, or confined to the bundle sheaths in the form of coloured streaks. It may also appear early or late in the development and is either temporary or permanent. Internodal colour is always dominant to colourless, and either one, two, or three factors are implicated, giving 3:1, 7 or 27:37 ratios respectively.

Inheritance studies of height indicate that one or several factors are concerned. Shortness may be a simple dominant to tallness, or tallness may be a simple dominant to shortness. There is also a correlation between height and flowering duration. The indications

are that this correlation is positive in early varieties and negative in late varieties. These two characters are also found to be associated with other characters such as length of ear and emergence of ear, and very definitely associated with yield, later and taller plants giving increased yield over earlier and shorter plants.

A bud may form in the axil of each leaf of the main stem, but normally only the lowermost buds from the crowded nodes at ground level develop into branches; thus, a typical tillered plant develops.

THE LEAF

The number of leaves borne on an axis is equal to the number of nodes. Since the number of nodes on the tillers is progressively fewer than on the main axis, the number of leaves on a tiller is correspondingly lower.

The first leaf of the plant is the sheathing leaf or coleoptile. The second leaf, emerging through the lateral slit of the coleoptile is reduced in size and has practically no blade. The remaining leaves are normal, except the uppermost or "flag," which is slightly modified. The bud—a potential tiller—is enclosed in the prophyll. The normal vegetative leaf has sheath, ligule, auricles, and blade.

The Sheath

The sheath is always present, encircling the whole or part of the internode from the pulvinus upwards. At the base the sheaths tend to exceed the length of the internodes and consequently enwrap the base of the succeeding sheath to a variable extent. From the tenth leaf upwards, however, the internodes are longer and the sheaths relatively and progressively shorter than the internodal length. Growth of the sheath is mainly from the base and may continue after the blade has attained about its maximum length. The sheath is split to the base, is finely ribbed, and is more or less glabrous. Colour, if any, may be confined to the base or may be distributed through the sheath, and may be visible either on the outer surface or on the inner surface, or both. The pigment occurs in the epidermal cells, in tissues surrounding the bundles, or distributed throughout the parenchyma.

Ligule

The ligule is present in almost all varieties of paddy; it is membranous and tends to split as it develops. The ligule may be colourless or coloured a faint pink or purple. A coloured ligule is always associated with colour in the sheath.

Auricles

The auricles are situated at the junction of the sheath and blade and are sickle-shaped. Long, slender teeth are normally present on the convex face of each ligule. Colour, if present, is always associated with colour in the pulvinus. If the auricles are coloured, so also is the sheath, but the converse is not true. Some strains of paddy are devoid of auricles.

The Blade

The leaves are long and narrow, usually pubescent or hispid, with a distinct mid-rib, but varying considerably in length. The leaves of many varieties are coloured, the colour being usually concentrated in the mid-rib region and on the margins, though occasionally the whole leaf is coloured.

The uppermost leaf, or "flag," of the axis possesses a blade always shorter and broader than the lower leaves. As the panicle emerges from the sheath, its blade is nearly parallel to the panicle axis. After the panicle has emerged the blade falls, ultimately standing either at an acute angle to the axis, more or less horizontal thereto, or definitely drooping.

INFLORESCENCE

The inflorescence is a spikelet borne on a long peduncle. The rachis bears branches, either single or in pairs, from which arise the spikelets. The number of spikelets on a panicle varies considerably with the variety—from a few to some hundreds. The spikelet, or flower, is borne on a short stalk, the pedicel. There are two short, rudimentary, bristle-like outer glumes, and the flower is enclosed in two inner glumes—a boat-shaped flowering glume or lemma provided with five nerves, and the palea, similar in size and texture to the lemma but three-nerved. Both the lemma and the palea may be awned or awnless.

The flower consists of two small, oval, thick, and fleshy bodies, the lodicules, situated at the base of the ovary. Unlike other cereals, paddy has six well-developed and functioning stamens provided with short filaments and a pistil with a plumose stigma. The ovary is somewhat longer than broad, smooth, and bears two styles and sometimes a short, rudimentary third, the three sometimes growing together at the base.

The rudimentary panicle may be felt as a swelling in the stem before the rachis develops, at the time when the stem grows rapidly. Finally, the peduncle elongates and the panicle appears. The latter, usually, fully emerges within a week.

FIG. 3
The rice panicle

The time of day when the flower opens and the period of flowering depend on the humidity and temperature, and also sometimes on the variety. The glumes become extended and the stigmas protrude followed rapidly by the bursting of the anthers, or they may dehisce before they are extended at all, in which case the stigmas have probably become pollinated before extension. Normally, however, the pollen is liberated while the spikelet is opening and rarely later. The position of the stigma in relation to the anthers when both are

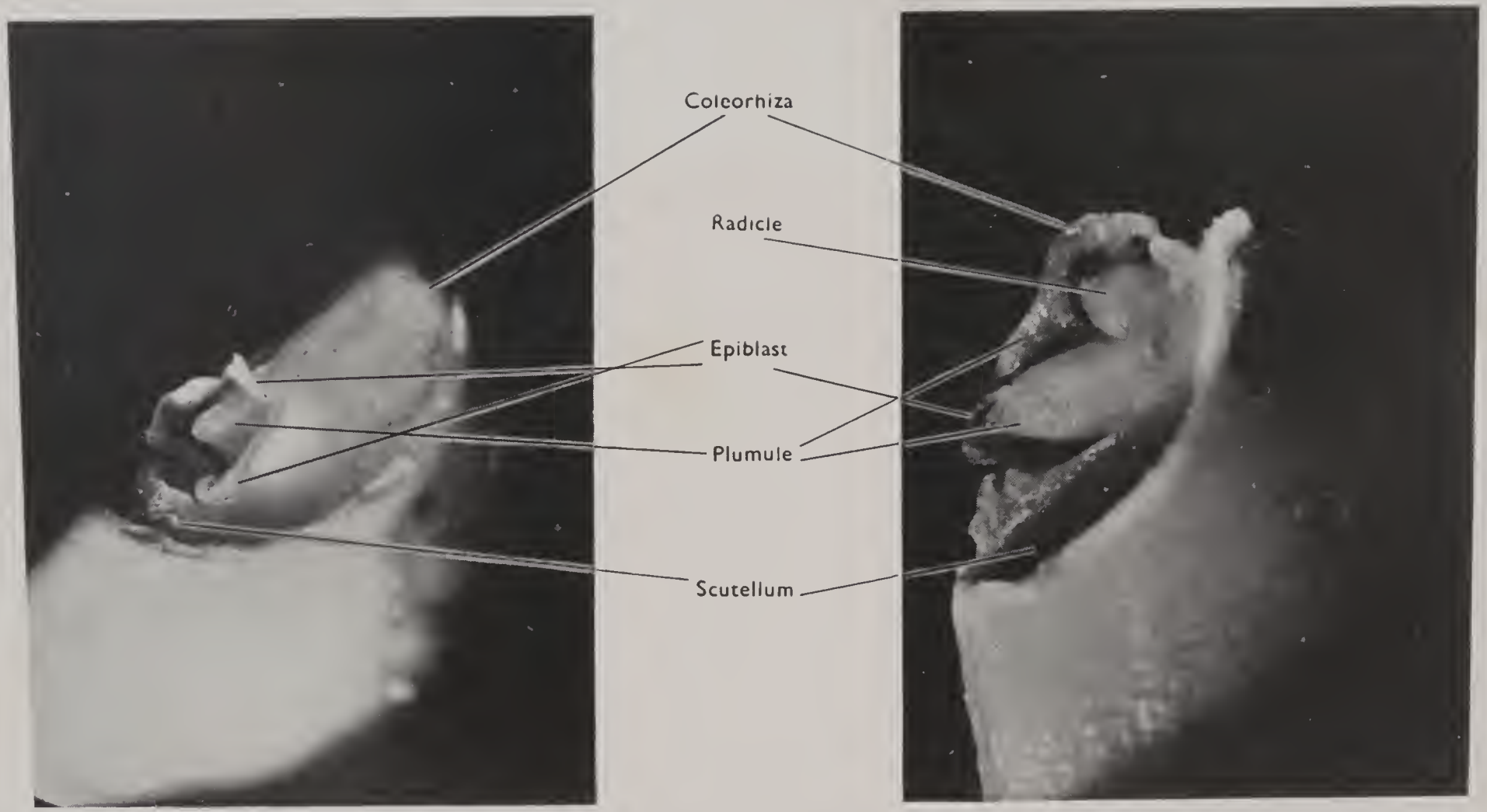
FIG. 4
Inflorescence of rice

extended is such that the pollen would not readily fall on the stigma. Cross-pollination is therefore possible and does indeed take place to some extent, the amount doubtless depending largely on climatic and varietal differences. Normally, the amount does not exceed 1 per cent, although as much as 30 per cent has been observed in some instances. Lord,[144] in a carefully controlled experiment found that in two climatically different districts in Ceylon, the amount of natural crossing varied from 0·34 to 0·67 per cent.

The flowers open from the tip of the peduncle downwards, over a

14. Watering fields from a well, Madras

15. Flooding and ploughing paddy fields in China



16. Dissection of germ of rice grain

period of a few days. The time they remain open doubtless depends on air humidity, the period may be from as little as six minutes to rather more than an hour. While the flowers may open at any time of the day, more usually they open in the forenoon. Burkill[35] observes that flowers opening in the afternoon are quite likely to do so with anthers already dried; but adds that opening so late is unusual and occurs only in dull weather.

Naturally, the flowering period should be as short as possible so that the whole crop becomes evenly ripe. While there is no practical control over the length of flowering time, it is conceivable that some strains with short flowering periods may in certain cases be advantageous. The period from flowering and ripening of the grain is normally forty days; there are, however, varieties that mature in less than a fortnight from flowering, and others that take over two months to ripen.

Santos[227] summarizes the morphology of the mature grain as follows. The mature grain coat consists of a filmlike covering composed of the following structures: the ovary wall or pericarp, the inner integument and nucellus which are pressed together flatly in a somewhat compact form. The kernel is oblong oval, usually smooth and glistening, whitish or translucent white, with or without abdominal white. Sometimes it is red or purplish-black. The endosperm is built up of thin-walled, elongated parenchyma cells filled with starch grains and some protein substances. The outer part of the endosperm is limited by a layer of rectangular cells known as aleurone cells, which are rich in proteins and fat or oil globules.

During the ripening process the spikelet becomes shorter and turgid. At this "milky" stage the embryo is fully developed and the endosperm cells filled with a watery sap in which starch grains are suspended. During this period of development the colour of the lemma and palea changes from pale to dark green, due, according to Santos, to the resorption of some of the contents of the several layers of the ovary wall and their subsequent compression due to the enlargement of the endosperm through which the chlorophyllous layers become more conspicuous. The spikelet then gradually loses its green colour, the endosperm becomes tough and waxy, the hull contracts, the cell layers become considerably distorted, and the spikelet develops into a hard grain.

The paddy grain (caryopsis) is enclosed by the lemma and palea (the "hull") to which it closely adheres. The general appearance of the mature rice grain is so familiar as to need no description. Its colour is usually that of the pericarp, although in some varieties the colour is also found in the endosperm. In the white varieties of rice

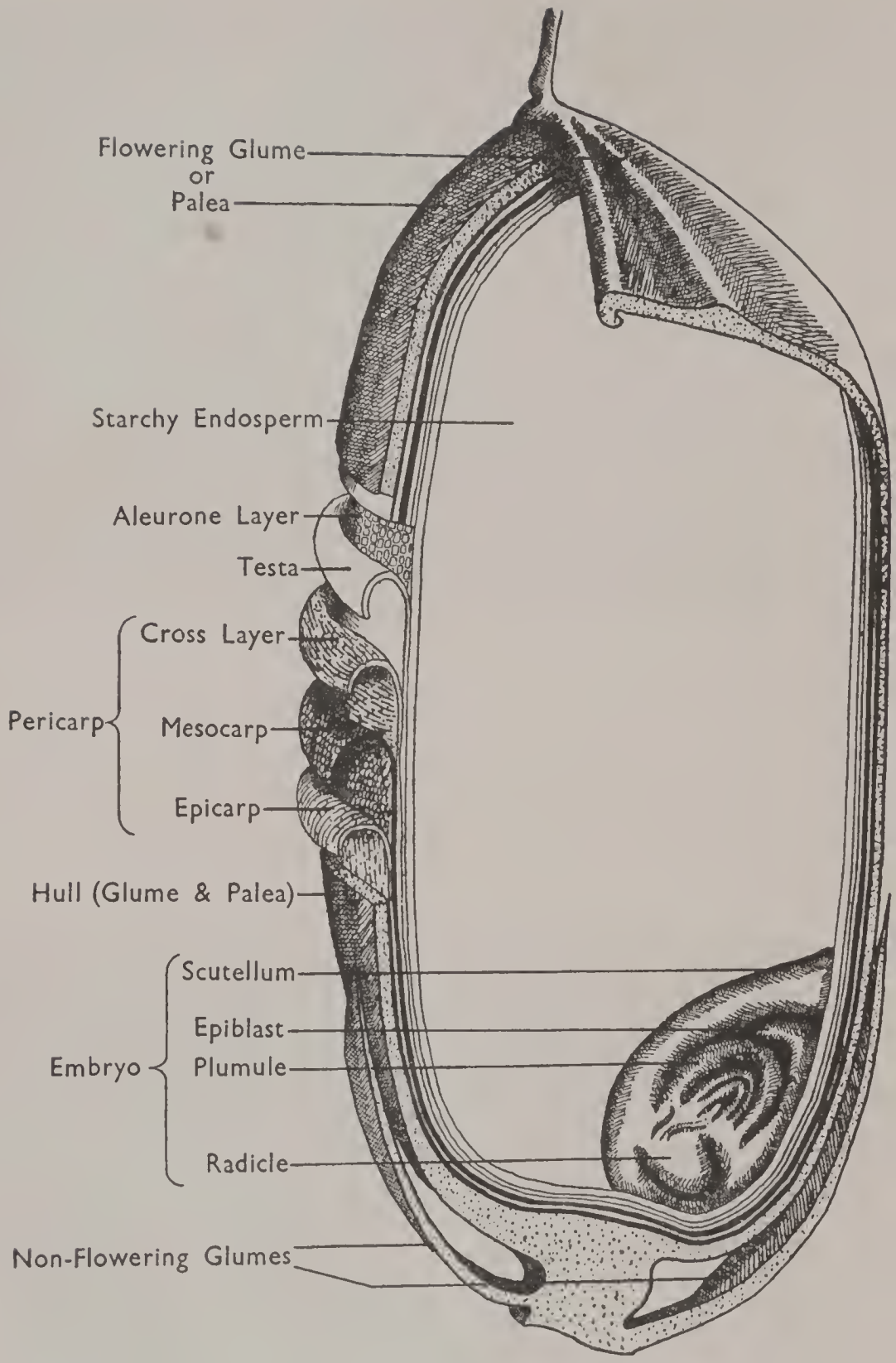


Fig. 5
Structure of the rice grain

there is usually a chalky, white portion at the middle ventral side, known as abdominal white. While the translucent, waxy, white appearance of the endosperm is general, occasional grains are found that appear dull, due to the fact that the endosperm is starchy on the outside and horny within. Grains with dull areas here and there are also not uncommon.

The main points of the morphology of the mature rice grain as described by Santos are as follows. The aleurone layer is composed of a single layer of quadrangular or rectangular parenchyma cells with thin walls. Within the aleurone layer at the dorsal side there are two short layers of polygonal parenchyma cells. The endosperm is built up of thin-walled parenchyma cells which are generally elongated radially. The endosperm cells in the sector towards the ventral region, which corresponds with the part occupied by the abdominal white, contain practically only starch grains. The protein contents of the endosperm cells mixed with the starch grains decrease proportionately from the periphery towards the region of the abdominal white.

The embryo is about one-third the length of the caryopsis, and located near the base towards the lemma or ventral side of the grain.

> In the middle part the plumule and primary root are arranged in the form of a capital L, the plumule corresponding to the long arm, the primary root corresponding to the short horizontal arm. These are joined to each other by a short stem, more or less at right angles, and embedded or surrounded by a mass of thin-walled polygonal parenchyma cells, which form the scutellum, epiblast, and coleorhiza. The ventral side of the embryo is protected by the prolongation of the aleurone region from the upper part of the embryo to the base and serves as an epidermis. This epidermis in turn is covered by the pericarp, which is pressed together with the seed coats.

The plumule or primary bud is somewhat ovate in outline, pointing obliquely away from the apex of the grain. It is composed of a minute growing point, one or more foliage leaves, and a leaf or coleoptile which encloses the growing point and immature foliage leaves which are attached to the upper end of the hypocotyl. The plumule is bounded at the inner side by the scutellum or cotyledon, which lies next to the endosperm and is attached to the hypocotyl. The epiblast is seen as a protruding structure which extends towards the upper end of the tip of the plumule and overlaps with the upper end of the scutellum. The epiblast is devoid of vascular tissue. Between the plumule and the primary root there is a short stem, the hypocotyl, which terminates at the anterior end in a short-growing point and at the posterior end into the primary root.

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LIBRARY

The outermost layer of the scutellum, towards the endosperm, consists of radially elongated thin-walled parenchyma cells, which are arranged somewhat in a palisade form. This layer is known as epithelium. The epiblast, like the scutellum, is composed of thin-walled rectangular or polygonal parenchyma cells. It is surrounded by the epithelium.

Some knowledge of the morphology of the mature grain is necessary to an understanding of the distribution of protein and fat, and of vitamins that are distributed in varying amounts in different parts of the grain. While the cells constituting the greater part of the endosperm contain practically only starch grains, the parts of the grain commonly designated "the germ" and the pericarp contain varying but considerable quantities of protein granules and deposits of fatty cells. In milling the germ is usually knocked off together with the scutellum, while in the polishing process the pericarp is removed with the remains of the embryo and the aleurone layer. This matter is treated in greater detail in the chapter concerning nutrition.

GERMINATION

Properly ripened and harvested paddy should reach a maximum germination of nearly 100 per cent when it attains the correct condition of maturity. Newly harvested seed has a low germination; with storage this will increase to its maximum, thereafter the germination capacity will fall off rapidly. In British Guiana, for instance,[200] with a six-month variety, germination was very poor for at least a month after harvesting. Germination then improved rapidly and approached the maximum of nearly 100 per cent about two months from harvesting. This high figure was maintained for about five months, after which the viability began to fall off gradually up to a period of eleven months after harvest, when germination practically ceased. At germination peak hand-threshed paddy gave practically 100 per cent germination as compared with about 90 per cent with machine-threshed paddy.

The resting period, during which germination has not attained a high figure, depends on the variety. Lord[142] has shown that varieties which have a long maturation period in the field require a correspondingly long resting period, and that the seed will therefore fail to germinate immediately after ripening and harvest. On the other hand, quick-growing varieties may require no resting period.

ENVIRONMENT

Considerable differences in growth are found under varying conditions; investigators frequently find that varieties that achieve a con-

siderable reputation in one country prove extremely disappointing when cultivated in another country. This was found to be the case with the early-maturing varieties from Japan when grown in Malaya; and experience in Burma has been similar. The Department of Agriculture, Burma, reports:[201] "Of exotic paddies over a hundred have been tried. The sub-tropical ones, as represented by the rices of Japan, Spain, Italy, and America, which are now so much in demand in Europe, have all proved precocious when grown under the tropical conditions of Burma, and have given yields barely half those of local selections. The purely tropical exotics have shown no superiority in quality or yield over pure lines isolated from indigenous types."

There is probably no important cereal crop that is more influenced by environment than paddy. This is a point of considerable importance in the consideration of the extension of the world area under this crop. It is probable that the areas suitable are far more extensive than is usually supposed. The bulk of the world's production is grown in the humid regions within the tropics, yet high yields are obtained as far north as Manchuria, about 45° north of the Equator, and as far south as New South Wales, about 35° south of the Equator. It is said to ripen at an altitude of 7,000 feet in Kashmir.

WATER REQUIREMENT

Varieties exist which grow satisfactorily under "dry" conditions, while others demand water for their development, and others again will grow on dry or on flooded land. The "dry" varieties, however, will not tolerate arid conditions, so that, in practice, their cultivation is restricted to regions where there is an assured rainfall over three or four months.

The depth of water for optimum growth of the "wet" varieties differs somewhat with the variety under cultivation; while some do best in water in movement, others will thrive in stagnant water and others will withstand flood water up to twenty feet in depth. The great majority of varieties demand fresh water, but there are a number that will tolerate considerable quantities of sodium chloride in the water.

Among the "wet" rices there is considerable variation in resistance to drought and flooding. Graham[87] places such varieties into three main groups in regard to their water requirements, viz. drought-resistant, normal, and flood-resistant, and states that the highly drought-resistant varieties can exist from twenty days to one month without water, while the longest period that a paddy can withstand

flooding is for about fifteen days. He suggests that the probable explanation of the phenomenon that among the late varieties both drought-resistant and flood-resistant varieties occur, may be that the danger of flooding to which the late varieties growing in the lowest fields are exposed in their early stages, and the late date of maturing, occurring long after the seasonal rainfall has ceased, have evolved a type which may be both flood- and drought-resistant.

The depth of water required by the plant depends on the variety; in general, however, it has been found that where the water is too deep for the particular variety, tillering is reduced, and this adversely affects the yield. The deep-water varieties are chiefly to be found in Bengal, Assam, and Burma.

HEIGHT OF PLANT

Apart from the so-called floating varieties, the ultimate height of the paddy plant is from four to six feet. Many of the tall varieties are weak in the straw and are therefore unsuited to situations subjected to high winds or rapid movement of water. At the other end of the scale are the dwarf varieties, growing to a height of not more than two feet. Kikkawa[136] considers that the dwarf varieties have little practical value, adding that they are often grown for the sake of curiosity. Graham[87] observes that as far as the Central Provinces are concerned, the short habit is associated with poor tillering and a small panicle. Kikkawa found that there is a correlation between the height of the plant and the tillering and weight of ear, tall plants giving more tillers and a heavier ear than do short plants. The present writer has been unable to trace any such relationship in a large number of varieties tested by him in Malaya between the years 1914 and 1920. Furthermore, he found that the dwarf varieties produce as many tillers as do the tall varieties.

The deep-water varieties, or "floating rices," are usually sown broadcast during the months March to May and are harvested at the end of the year. The monsoon in June gradually floods the land until in places it reaches a depth of twenty feet. As the level of the water rises the paddy grows, so that its tip is maintained above flood level. Ramiah and Ramaswami[194] state that the stems grow rather zigzag under the water and have a tendency to crawl on the surface and this habit is responsible for their being called "floating." Tillers and roots are produced at nodes above the stem base, such roots supplementing the rather poorly developed root system of the plant. Should the flood water fall and leave the long weak stems prone on the mud, there follows a rapid development of roots at the nodes.

TILLERING

The number of tillers is approximately constant for any one variety under comparable conditions, but tillering is influenced by cultural conditions, spacing of the plants, weeds, and water supply. If the seed is not planted too deep, tillering commences about a fortnight from sowing. The plant may continue to form tillers for a short period, or their formation may continue until shortly before the inflorescence appears. The ultimate number of tillers is not necessarily the maximum number formed, i.e. during growth of the plant a number of tillers may be formed which do not produce inflorescence, and in fact, some of them die before the plant reaches maturity. If the tillers are few in number and produced within a short period of time, the ripening period of all is approximately equal; if the tillers are numerous and/or produced over a lengthy period of time, a variable number of unproductive tillers must result. A large number of tillers is therefore not necessarily conducive to high yield, for it may result in unequal ripening. It is desirable that all earheads should ripen at the same time. In a variety which does not tiller profusely it is usually possible to obtain the approximate number of earheads by planting more closely.

Ashby observes[12] that deep cultivation of both "dry" and "wet" paddy checks growth of the plant and delays tillering, resulting in late and uneven ripening, due probably to late-formed tillers, which are not, however, too late to develop normal ears.

In some varieties the stems are more or less stiff and the resulting habit of the plant is compact. In other cases the stems are more prostrate and the plant habit is therefore spreading. Ramiah found that the compact habit behaves as a simple dominant to the spreading habit. In plants with the compact habit the basal internodes were always short while in those with a spreading habit the basal nodes were definitely longer and the tillering succession more obvious.

LODGING

Lodging may be the result of environmental conditions or may be specific to the variety. Walton and Morris concluded that in rich soil the chain of sequence appears to be hyper-nutrition, low carbon-nitrogen relation, a preponderance of vegetative growth, and consequent straw weakness. On poor soils the reverse is true—a high carbohydrate-nitrogen relation, a reduction in the proportion of vegetative growth and straw strength. Hector[101] has drawn attention to the work of Revera (1916) on wheat, who concluded that

lodging was due to the high water content of the tissues, and of Weldon (1928), who showed the reverse condition, i.e. lodging resulting from low dry matter content per unit length of culm. This may be the result from a relatively low content of lignin and various reserve materials, such as disaccharides and polysaccharides, or from the development of relatively small slender culms. This condition in turn is due to a low carbohydrate-nitrogen relation, the result of shade, hyper-nutrition, or relatively high temperatures. He adds that though nitrogenous manures decrease the silica and ash content, the lignin is increased. Experiments by Tubbs have shown that nitrogen deficiency tended to strengthen the lower nodes and concluded that weakness of the internodes is due to loss of strength in the mechanical tissue, and that this mechanical tissue can only develop effectively in the presence of a sufficiency of potassium.

External factors responsible for lodging are shading, hyper- and unbalanced nutrition, temperature, and disease. If the plants are crowded, light is shut off from the stems, resulting in some etiolation at the base of the plant, the cell walls of the tissues being smaller and thinner, and the mechanical tissue much reduced. Excess nitrogen and water produce a similar result, while lack of potash induces weakness in the mechanical tissue. Relatively high temperatures result in much the same condition, and several fungus diseases may cause stem weakness.

Hector also refers to the internal factors responsible for lodging which are specific to the variety. In general, somewhat stout, short-strawed varieties are more resistant, as may be expected, but some of the long-strawed varieties are also resistant. According to Bhide and Bhalerao (1927), the more resistant types have stems with a thicker band of sclerenchyma at the periphery than have strains that tend to lodge, more fibro-vascular bundles, and exhibit, in particular, a narrow layer of small sclerenchymatous cells behind the air cavities, more or less linked to the sclerenchymatous sheaths of the bundles which lie between these cavities. These layers, they state, are usually absent in varieties prone to lodge.

MATURATION PERIOD

In most Asiatic countries of rice production considerable importance is attached to the classification of varieties of paddy according to the time of ripening. The date of sowing must depend on the water supply and climatic conditions; the classification of varieties according to time of ripening must therefore be of local interest only, while the total number of days from planting to maturity is the real

measure and is likely to lead to no misunderstanding. Taking maturation period as the measure, Graham[87] states that in the Central Provinces early varieties mature in 121 days, the range being from 106 to 145 days; the medium varieties in 125 days, the range being from 110 to 169 days; and the late varieties in 133 days, the range being from 119 days onward. The period between sowing and the appearance of the ears in the three classes is almost identical, viz. 87, 90, and 91 days, so that the earliness or lateness of a variety depends not so much upon the vegetative period of growth as upon the reproductive period during which the fruit matures and ripens.

The maturation period of a paddy may be anything between 90 and 260 days, and within limits maturation period varies with environmental and climatical conditions. Generally, tillering varies with maturation period, i.e. varieties with a long maturation period produce more tillers than those with a short maturation period. But even on this point one cannot be too dogmatic, for it is obvious that where conditions are particularly suitable for a particular variety, that variety will produce a greater number of tillers than it would under less favourable conditions. Still, the general principle can be maintained—short maturation period, fewer tillers and small crop; long maturation period, many tillers, heavier crop. It has been observed[148] that the yields of rice in Formosa are appreciably lower than in Japan, one reason advanced in explanation being that the Formosan varieties have a shorter growing period.

Burkill has observed[35] that there are two vaguely defined groups depending on their behaviour in flowering, some races completing a definite period before flowering, others flowering when a certain minimum time has elapsed; climatic conditions change in a way which stimulates their flowering. "Thus it is," he concludes, "that two plots of certain rices may be sown side by side, a month apart, and both will flower at the same time: yet two plots of other races, so sown, will keep their distance in time regardless of the coming of brighter weather."

STERILITY

Sterility may vary from a few empty glumes to the entire panicle. Lack of fertilization due to unfavourable weather conditions may account for the occasional empty spikelet, or it may be due to inherited degeneration. The top of the panicle may exhibit rudimentary spikelets, white and papery in appearance, which tend to dry up and break down shortly after they emerge. This condition, known as "sponginess" in Java, may be due to environment, but in

most cases appears to be due to abortion of both the anthers and the ovaries.

Sterility of the entire panicle may be due to borers, eel worms, fungus infection, physiological condition, or it may be inherited.

Chapter V

VARIETIES AND THEIR CLASSIFICATION

Chromosomes—Reason for Large Number of Varieties—Types Favoured in Different Countries—Influence of Mechanized Cultivation on Varieties Grown—Hard and Soft Varieties—Systems of Classification of Varieties—Suiting the Variety to the Environment.

THE varieties of cultivated rice are legion and the variation of characteristics exhibited by them enables the crop to be grown with success over a wide range of climatic and cultural conditions; from dry land, in more or less arid conditions with irrigation, to deep undrained swamps, and in varying depths of water.

CHROMOSOMES

The basic chromosome number of rice is 12 pairs; multiples of this number occur, plants being found with 12, 36, or 48 chromosomes. Chromosome numbers are related to the size and vigour of the plant. The plant with 12 chromosomes is very diminutive and completely sterile; those with 36 and 48 chromosomes are comparatively larger and better developed than those with the normal 24. Chromosome numbers, therefore, are related to the size and vigour of the plant.[193]

The cultivated varieties of paddy are derived from hybrids of *Oryza fatua*, *O. minuta*, and other wild species.[35] Although paddy is a self-fertilizing plant, natural crossing is not uncommon, and is greater in the wild types than in the cultivated forms. From these wild forms new forms were developed, giving rise to the numerous varieties now under cultivation.

REASON FOR LARGE NUMBER OF VARIETIES

The perpetuation of such a large number of varieties is probably due to the Asiatic custom of harvesting ear-by-ear with the implement (*pangani* in the Philippines, *pisau penuai* in Malaya) which cuts the ears of paddy singly. Copeland[51] suggests that this is the original harvesting implement and records its widespread use in the

Philippines and in Java. The natural result of harvesting the crop ear-by-ear is that the attention of the harvester is naturally drawn to any striking variation from the normal. The present writer's experience is that the Asiatic cultivator is attracted by differences in varieties and is prone to cultivate any paddy which strikes the eye as different, often merely to impress his neighbours. (Has not one seen a similar vanity exhibited by gardeners the world over?) It is, therefore, reasonable to ascribe the existence of this wide range of varieties as due mainly to the traditional method of harvesting.

Native curiosity, however, was not solely responsible for this multiplicity of varieties, for under primitive conditions the cultivator was faced with the necessity of finding varieties which would prove suitable for cultivation over a wide range of cultural conditions, and these varying conditions may, and indeed do, exist in close proximity within small areas of country.

TYPES FAVOURED IN DIFFERENT COUNTRIES

The types of paddy favoured in a country depend on climatic and cultural conditions, and on whether the rice is destined for export or for local consumption. Racial preferences are very pronounced. In the Philippines, for instance, a long-grained, hard rice is favoured, white and highly milled. The Japanese demand is for a short-grained, semi-glutinous rice; while of the total production in India and Pakistan, about 13 per cent is long-grain, 32 per cent medium-grain, and 55 per cent short-grain rice.

In Burma[201] the cultivator recognizes three groups of paddy, classed according to maturation period; they are:

Kaukyin or early varieties, with a maturation period from 100 to 150 days.

Kauklat or varieties with a medium-length maturation period, from 150 to 170 days.

Kaukkyi or varieties with a long maturation period, from 170 days and upward.

Douglas[70] divides types of rice into three categories:

(1) Relatively long and bold type, known as Carolina rice.

(2) Long, thin, cylindrical grain, known as Patna.

(3) Short, stout grain, known as Spanish-Japan.

In Indonesia[76] there are four main grades of milled rice; the highest quality being obtained from a long-grained, awned paddy with an indifferent yield. The second quality is a slightly smaller grain, while the third grade, which is in main demand in the area, is a short-grained rice. The fourth grade is a glutinous rice.

In Malaya, local varieties are divided into four categories, depending on the size and shape of the grain, though no exact limits appear to be made as to the dimensions of the grain, or the ratio of length to breadth.

The *Seraup* type, which has a distinct shoulder on the anterior extremity of the grain. This type is the most acceptable to millers because of its weight and good milling qualities. Varieties in this type have a long maturation period, over 230 days, and are amongst the highest yielding varieties. The size and shape of grain may vary widely between varieties, especially in length of grain.

The *Radin* type, which is very uniform in outline, and is of medium length. Less popular with millers because of its lightness and small size of grain, but it is popular with growers for home consumption. The maturation period is very variable, from 120 to 270 days.

The *Rangoon* type is a rice which is broad and thick in proportion to its length. It is unimportant. The maturation period varies from 120 to 180 days, according to variety.

The *Siam* type, with a very long and sometimes slightly curved grain. It is grown entirely for local consumption and is not favoured by millers. The maturation period of varieties may vary from four to seven months.

In practice, there is no hard and fast division between varieties that grow in water and those that grow on dry ground. There are many varieties of "wet" paddy that will not tolerate dry conditions and *vice versa*, but there are also many varieties that will flourish under either wet or dry conditions.

A feature of rice production in the United States is that while the short-grain varieties are almost exclusively grown in California, over 70 per cent of the rice produced in the other three important producing areas of Arkansas, Louisiana, and Texas are medium-grain varieties. Long-grain varieties amount to about 26 per cent of the production in these three southern states. But total production of rice is much larger in the three southern states than in California, so that of the total rice produced in the United States, about 58 per cent is medium-length grain varieties, 21 per cent long-grained varieties, and 18 per cent short-grained varieties.

It is of interest to observe that the short-grained varieties have grain measurements of about 5·5 mm. long and 3·2 mm. thick, so that they correspond with the *Midon* varieties of Burma, while the medium-grained varieties measure from 6·1 to 6·7 mm. long and 2·6 to 2·9 mm. thick, corresponding to the important *Ngasein* group of Burma, and the long-grain varieties with measurements of 6·6 to

7·7 mm. long, 2·0 to 2·6 mm. thick correspond to the *Emata* group in Burma.

The origin of practically all the cultivated rices of America is Asia; over five thousand varieties of paddy from various parts of the world have been introduced in the past thirty years, but very few of these have proved suitable for cultivation in the United States. Of the varieties at present widely grown, many are pure-line selections from certain of these importations, while a few are the result of crosses effected by the Department of Agriculture in the United States.

Considerable attention has been given in the United States to the improvement of varieties by selection and breeding to meet the needs of particular districts. It would appear that in common with most other countries, continual efforts are needed to maintain the purity of the stock seed distributed by the Department of Agriculture. Whereas in Asia this difficulty is often caused by the desire of the cultivator to grow several varieties, and by the smallness of the individual holding, in America a frequent source of trouble is the threshing machine, which is not always properly cleaned when it is moved from one farm to another, or has to thresh paddy of more than one variety.

Varieties of Japanese rice[139] are usually short and small-grained, the stem and leaves short and tough, and the leaves narrow. The experimental stations have distributed new and improved varieties, making it possible to grow satisfactory crops under the varying climatic conditions of the country. The early varieties are resistant to low temperatures and have been developed for cultivation at the higher elevations in the warmer districts, or where two annual crops are grown. The cool districts grow relatively tall varieties with a high weight of grain per ear, although the number of ears per plant is few. Where the summer is short and cool, short-stemmed types with many tillers are grown. In the warmer districts varieties are cultivated with less weight per ear, but the ears are numerous and the straw short. The same authority states that the problem of crop failure in low-temperature regions is being met by the selection of cold-resistant varieties, early sowing of the nursery, early transplanting, warming the irrigation water, and by improved fertilizer practice.

In regions of high temperature in Japan, a rank vegetative growth, lodging, and low yield are met by growing sound seedlings, transplanting at a suitable time, covering the plants with soil high in iron ions, and by improved fertilizer practice. Of varieties grown, the Norin varieties have been developed at the Stations. Strains of Asahi,

Aikoku, and Gimbozu are extensively grown, while other varieties distributed include Rikun No. 132 in Tohaku, Norin No. 1 in Hokuriku, and Aikoku in Kanto. In the warmer south-west districts Asahi is widely grown, the varieties in this region being well adapted to short-day conditions.

In Formosa efforts have been made and are still being made to breed varieties which are adapted to ascending and descending temperatures and hence are suitable for planting in the first and second half of the seasons respectively. The high-yielding variety Horai was introduced in 1922 and has proved very successful. It is stated that over 60 per cent of the cultivated area is now planted with this variety and that it contributes about 70 per cent of the total rice output of Formosa.

Soviet Russia aims at selection for earliness, moderate water requirement, and selection of varieties grown under conditions of flood and tolerant to saline soils. It is claimed that Assam types can supply the four types of plant needed by Soviet rice breeders.[73]

INFLUENCE OF MECHANIZED CULTIVATION ON VARIETIES GROWN

Many of the difficulties recently encountered in mechanization of paddy cultivation in British Guiana were found to be due to the unsuitability of the local varieties to mechanized conditions, and the production of new varieties is therefore being undertaken in this region to overcome these objections. It is pointed out[199] that the present varieties are suited to the requirements of a transplanted crop where free tillering is desirable. Where the crop is drilled or broadcast and harvested by machinery, tillering has proved to be a distinct disadvantage, as it causes uneven ripening, reaping is delayed, and there is a greater tendency for the crop to lodge, thereby increasing the difficulty of using harvesting machinery.

Furthermore, the British Guiana experience is that the local variety has the habit of prolonging or shortening its maturation period according to the weather, so that, regardless of the date of sowing, maturation takes place at one time. It is therefore impossible to arrange a series of sowings with the object of prolonging the harvesting period. Another objection to the local varieties is the length of straw, a feature that not only encourages lodging but increases handling costs and interferes with the working of the harvesting machinery. It is considered that the ideal variety for mechanized rice production should have a stiff, stout straw, should not tiller freely, and should not readily shatter. The grain should be long, to facilitate the separation of red rice by mechanical means

(red rice usually having slightly smaller grains than the cultivated varieties), and because long-grained rice is more popular on the markets.

It would seem, therefore, that any widespread development in mechanization will necessitate a reconsideration of the present ideas on desirable qualities in paddy.

HARD AND SOFT VARIETIES

Varieties are divided into two main classes: those with a hard, starchy grain having a vitreous fracture, and those with soft, dextrinous grains having an opaque fracture. The first named form the rices of world commerce, the latter being of more local importance.

The so-called glutinous rices possess a dull and soft grain, the cut surface being described as paraffin-wax-like in appearance. The straw is usually soft and pliable, making it more valuable but also more liable to lodge, the grain is usually large and in many varieties coloured, the colour in some cases being confined to the epidermal layer, in others extending throughout the endosperm.

These "glutinous" rices, in fact, contain no glutin; the sticky nature of the cooked grain is due to the constitution of the carbohydrates in the endosperm, although opinion appears to differ as to the exact nature. The commonly accepted belief is that the endosperm is not entirely filled with granules of starch, but that it contains soluble starch and dextrin, with some maltose. Burkill[35] considers that this deposition of dextrin in the grain instead of starch can be regarded as a deferring of ripening, adding that it is obvious that on the whole it is a very small change and likely to be due to the selection work of man. He quotes Mitra[161] in stating that the grains of some "glutinous" rices seem to become non-glutinous during storage. In many Asiatic countries a specific name is given to "glutinous" rices as distinct from the general name for rice, while they also recognize intermediate forms between the hard rices and the "glutinous" rices, which they designate "soft rices."

The characteristics of "glutinous" rice is that when treated with iodine the starch stains a yellow- or reddish-brown colour (as does dextrin) instead of the usual blue reaction of starch. Wickizer and Bennett[271] state that it is wrong to assume that because the colour reaction is that of dextrin, *Oryza glutinosa* contains dextrin instead of starch, and affirm that, in fact, it does contain genuine starch. Compared with the hard rices, *O. glutinosa* varieties are usually of poorer quality, the protein being lower though the fat content is distinctly higher.

When boiled, the "glutinous" rices become sweeter, sticky, and cloying, for which reason they are not eaten as a cereal with the usual curry; they are, however, widely used in the preparation of special dishes, pastries, cakes, and for ceremonial purposes.

Oryza glutinosa is practically unknown in international trade, yet it is widely grown in Asia where a large number of varieties are recognized. Cultivators usually grow a small area under a much-prized local variety for home consumption or local sale at a premium over the hard rice. About 10 per cent of the rice produced in China and Japan is stated to be *O. glutinosa* and it is cultivated in India, Burma, Java, and the Philippines—and doubtless in many other countries. On the other hand, Graham[87] states that "so far as the present collection has gone, no examples of glutinous rices have been found in the Central Provinces." The writer found no glutinous rices in British Guiana, and it is doubtful whether there are any in either North or South America. In no country does "glutinous" rice replace hard rice. It is probable that the cultivation of these special rices will persist, but they are unlikely to assume any importance.

SYSTEMS OF CLASSIFICATION OF VARIETIES

Successive writers have pointed out the desirability of instituting an internationally recognized system for the classification of varieties of rice, yet little advance in this direction has been made. Copeland refers to the resolution presented at the Rice Congress at Valencia in 1914 urging the "formation of a real botanical classification of the varieties of cultivated rice," yet although valuable contributions have been made towards this end, both before and since Copeland wrote, nothing has been achieved on an international level towards the adoption of a comprehensive international system of classification. Indeed, in many countries where investigations on rice have extended over many years, no attempt has been made to classify the local varieties. Classification in Burma is largely based on millers' requirements; Malaya has been influenced in the same direction. There is much to be said for this system based on local purposes. In many other countries classification has been made on physiological characters—maturation period, height, tillering, and so on. These characters are valueless as a basis for international classification, because the behaviour of a variety differs according to climatic, soil, and other conditions.

Valuable contributions towards botanical classification have been made in India, which are discussed later, and much good work has been done in Japan and elsewhere. But these attempts at classifica-

tion are usually restricted to the country in which the investigator works, no attempt being made to correlate results in different countries and to agree on a comprehensive system that shall be internationally recognized. The Rice Study Group of the Food and Agriculture Organization of the United Nations recommended[212] that the Food and Agriculture Organization "prepare a catalogue of breeding stocks. . . . The importance of a large collection including all species and wild types is well recognized. As South-east Asia is the original home of rice, it should be highly useful to explore and collect all species of *Oryza* found in these regions." But, if the work of collection is not to lead to the creation of an interesting but useless museum, surely the work must be preceded by agreement on classification, so that workers in different countries may be able to make intelligent use of the collection.

During the past century many attempts have been made to devise a botanical classification of rice varieties. Many of these systems were so rudimentary as to be of little practical value, or of only local significance. Gushchin[91] has pointed out many of the weaknesses of these attempts, amongst which he notes that but a small number of types are usually encountered in the classifications, and that there is no attempt to classify on genetic characters.

Kikkawa[136] suggests two systems of classification, one based on agricultural characters, or as he states it, "with regard to its cultivation," the second on the characters of the grain. His first system must be dismissed, for many of the characters upon which the system relies are variables; for instance, the two main divisions are Aquatic Rice and Upland Rice, but, as he himself points out, "we can hardly draw a line between common or aquatic rice and upland rice." His classification based on the grain has much to recommend it. The distinctive points are summed up as follows:

(*A*) Non-glutinous rice.
(I) Slender-grained. (II) Long-grained. (III) Short-grained.
(1) Large grain. (2) Medium grain. (3) Small grain.
(*a*) Common-coloured.
(*a*) Ordinary. (*b*) Scented.

(*B*) Glutinous rice:
(I) Slender-grained. (II) Long-grained. (III) Short-grained.
(1) Large grain. (2) Medium grain. (3) Short grain.
(*a*) Common-coloured. (*b*) Specially coloured.

Graham[87] presents a more critical view of the characters which are admissible for the purposes of classification. His simple classification is summed up by him as follows:

All rices fall into one of two groups, viz. rices with a green leaf sheath and those with a coloured leaf sheath. The second class may be sub-divided into those with a red leaf sheath and those with a purple leaf sheath.

These classes further sub-divide on their vegetative characters, those of the spikelet and those of the grain. In addition to these morphological characters, the time of ripening, though not definite enough to form a main point in the classification of rices from a large area, is of considerable local importance.

The necessity of confining the characters for classification purposes strictly to those that do not vary cannot be too strongly urged. Graham would admit time of ripening, at least for local purposes, but this character is extremely variable, depending on environment, water supply and control, method of cultivation, manuring, soil, and even variations of climate from year to year: in fact, upon almost every possible factor that may affect growth.

Kashi Ram and Ch. V. Sarvayga Chetty[192] in a study of the rices of Bihar and Orissa pointed out that most workers based their main divisions on classification of the grain, whereas the only truly satisfactory classification must be on qualitative characters. Most quantitative characters are difficult to use for this purpose because they are difficult to define sharply and are subject to fluctuations through changes in environment. They stress the value of colour characters as criteria, the primary divisions being based on the chemical constitution of the kernel, the presence or absence of clustering in the spikelets, length of the outer glume, and upon the presence or absence of elongated internodes such as occur in deep-water varieties. The subsequent divisions are based on the colour of the inner glume, apiculus, outer glume, kernel, and internode, in the order named. The ultimate classes are distinguished by differences in the size and shape of the grain.

In the working out of the above excellent basis of classification, its authors were probably influenced by previous work on this subject in India. Hector, for instance, many years earlier had classified varieties at Dacca on the following basis:

(1) Leaf-sheath, apiculus, and stigma coloured.
(2) Leaf-sheath, apiculus coloured, but stigma colourless.
(3) Apiculus and stigma coloured, but leaf-sheath colourless.
(4) Apiculus only coloured.

He adds, and Beale agrees, that it is doubtful whether (3) and (4) actually exist.

Development of the work in India is shown in the scheme devised

by Beale[27] based mostly on the characters of the grain. Certain standard types are defined, to one of which any variety must conform. Where varieties are similar, reference is made to floral and other characters.

Beale divides the varieties of Burma into five groups; they are as follows:

The *Ngasein* Group which comprises the largest number of Burma varieties. The grain is bold and hard and fairly translucent, though the defect known as "abdominal white" is inherent in many of the varieties. The milling out-turn is considered good and the type is popular. The type is defined thus: Short medium grain, apiculus prominent, straight. Shape obliquely obovate. Kernel usually translucent, sometimes with "abdominal white."

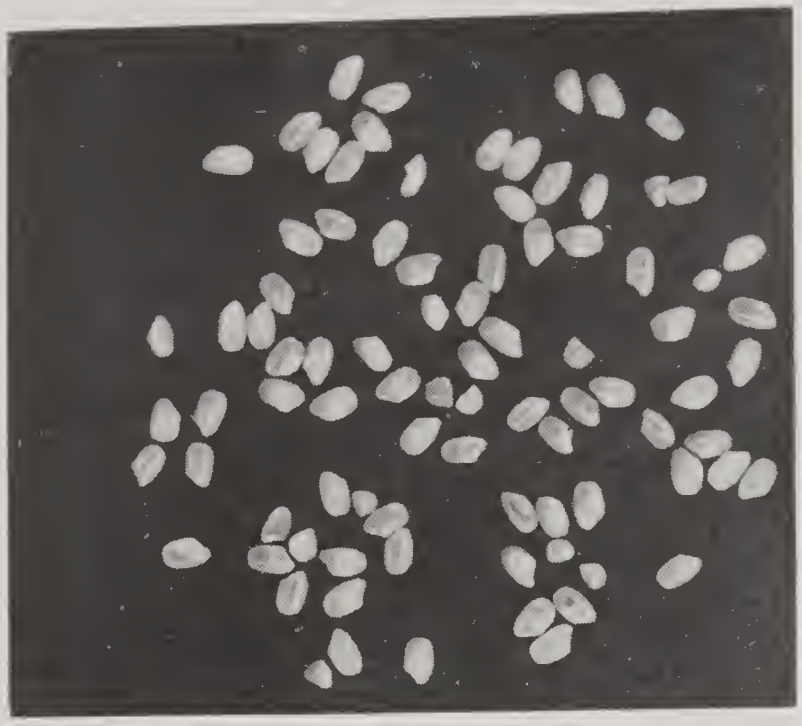
The *Medon* Group probably comes next in importance to the *ngasein*. It has a short plump grain and in spite of being softer and more chalky than the *ngasein* group, its milling out-turn is higher. Locally, it commands a higher price owing to it being considered more tasty and more easily digested. It does not travel very well, but there is a growing export for it in the East. The type is defined: Short, roundish, bold grain; apiculus-end round without a "beak," and usually hairy. Shape broadly elliptic, kernel opaque and chalky.

The *Emata* Group. The main character of this group is a long hard grain, in which the breakage on milling is high, but which gives an attractive rice capable of high polish. On account of the difficulty they present in milling, the lower qualities of *ematas* are parboiled. The type is defined as follows: Long, slender grain, apiculus very prominent and often curved. Shape of grain linear; kernel translucent.

The *Letywezin* Group comprises a large number of varieties. In appearance and character they lie midway between the *ematas* and *ngasein* groups. The grain suffers in milling, for which reason they are frequently parboiled. When parboiled, they find the same market as the *ematas*, and when milled as white rice they are classed as an inferior *ngasein*. The grain is described as slender, apiculus prominent but not curved; shape lanceolate; kernel translucent.

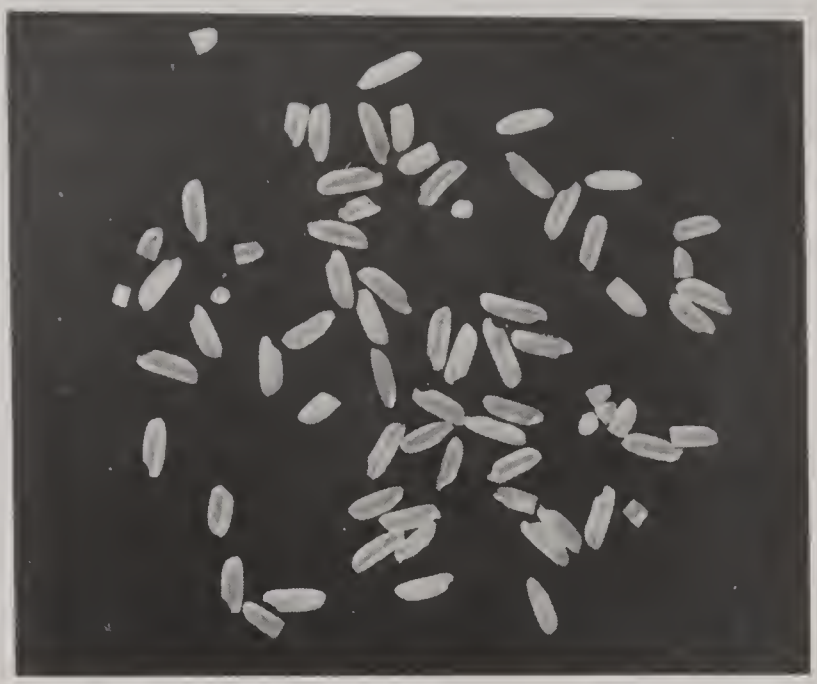
Varieties of the *Byat* Group do not play a very important part in trade. They are, however, grown in small areas and are much appreciated for home consumption. The grain is large and bold and mills well. The milled product is chalky in appearance and soft. The grain is broad and large; apiculus-end round, beak absent, usually hairy. Shape elliptic; kernel opaque and chalky.

Beale's five groups are more closely defined by him into seven types:

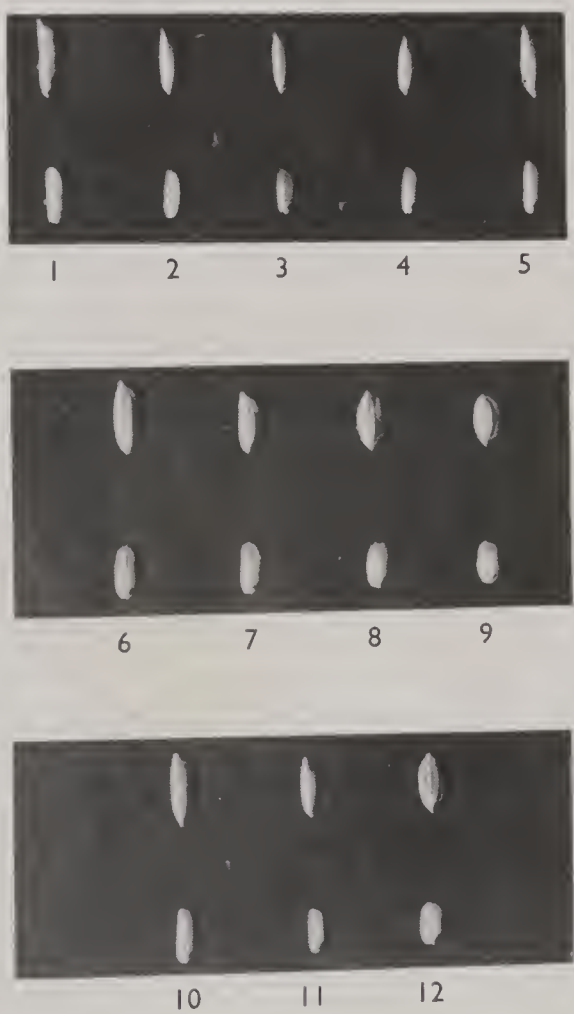


17. Commercial sample of Italian rice

18. Commercial sample of "Converted" rice from U.S.A.



19. Commercial sample of parboiled rice from British Guiana



20. Paddy and Rice from Some Types of *Oryza sativa*, L.

1. Patnai. 2. Chingrighusi. 3. Kalaktara. 4. Bhasamanik. 5. Indrasail (Winter Rice).
6. Type 28-8. 7. Type XA-97. 8. Type E-30-42 (1938). 9. Type D-17-88. 10. Emata. 11. Theikpan. 12. Khayangya.

- Stigma white
  - Apiculus *not* purple
    - *Type* 1. Leaf-sheath green outside, white inside. Leaf-blade green, stem green.
    - *Type* 2. Leaf-sheath inside and outside, ligule and margin of leaf-blade all faint purple.
  - Apiculus purple
    - *Type* 3. Leaf-sheath purple outside, white inside. Margin of leaf-blade purple.
    - *Type* 4. Leaf-sheath green outside, purple inside; leaf-blade margin green.
- Stigma purple
  - Apiculus *not* purple
    - *Type* 5. Leaf-sheath green outside, inside temporarily purple, usually late in development. Other parts *not* purple.
  - Apiculus purple
    - *Type* 6. Leaf-sheath outer surface purple, turning green later. Inner surface purple. Ligule may be purplish. Internode purple-lined or green. Margin of leaf-blade green.
    - *Type* 7. Leaf-sheath inside and outside purple. Ligule parts usually purplish. Nodes and internodes green or purple-lined. Margin of leaf-blade and midrib purple.

He adds that the difference between 6 and 7 may be a matter of intensity of purple colour, and it may be possible to eliminate 6, making 7 cover both. Colour of stem, of both the nodes and internodes, does not appear to be as important as that of the leaf-sheath.

Mention has been made of Beale's five groups. These are defined by length and breadth of grain, thus:

TABLE 6

DIMENSION OF GRAIN OF BURMA RICES

Group name	*Dimensions of grain*			
	With husk		*Husked*	
	Length in mm.	*Length breadth*	*Length in mm.*	*Length breadth*
Emata ..	Over 9·4	Over 3·3	Over 7·0	Over 3·0
Letywezin	8·4 to 9·8	2·8 to 3·3	6·0 to 7·0	2·4 to 3·0
Ngasein ..	7·75 to 9·0	2·4 to 2·8	5·6 to 6·4	2·0 to 2·4
Medon ..	7·35 to 8·6	2·0 to 2·4	5·0 to 6·0	1·6 to 2·0
Byat ..	9·0 upwards	2·25 to 3·0	6·4 to 7·35	2·10 to 2·5

Thus, there are five groups and seven types. It is claimed that within these thirty-five divisions any variety may find a place. It is

appreciated that the division of grain into five groups according to size and shape of grain may appear arbitrary, but it has proved to be a workable scheme in the largest rice-exporting country of the world, and as such merits consideration.

Objection can be advanced against any scheme of classification of rice, and the problem is undoubtedly complex. It is suggested that, in the first place, a simple scheme of classification be adopted which is capable of elaboration as a result of experience and by general consent of an international body.

SUITING THE VARIETY TO THE ENVIRONMENT

No expert can, by visiting an area, or by examining climatic conditions and the chemical nature of the soil, prescribe with any certainty the variety of paddy to which the situation is suited. He may, however, with reservations, indicate varieties which, after acclimatization, may prove suitable. The many factors influencing the growth of paddy are so complex, and so much is incompletely understood, that the vagaries of the crop can only be countered by the process of trial and error. A study of the literature on paddy-growing will reveal the many apparent contradictions, so that only by tests over comparatively small areas can the most suitable variety be selected. Furthermore, the selection of the most suitable variety for a given area does not depend entirely on which variety will produce the greatest crop; the selected variety must also be suited to the market that the crop is destined to find.

From the discussion of the cultural conditions of growth, together with a realization of the wide range of varieties, it will be appreciated that the cultivation of paddy is possible over a wide range of climatic and soil conditions. The task of selecting the right variety for any given area is extremely complex; its complexity will be lessened when the classification of varieties is standardized, and with the increase of knowledge of the requirements of the crop.

Chapter VI

PESTS

Importance of Pests—Stem Borers—Leaf Caterpillars—Paddy Bugs—Leaf Beetles—Grasshoppers—Root and Miscellaneous Insect Pests—Other Pests—New Insecticides.

IMPORTANCE OF PESTS

THE paddy plant is subject to insect pests at every stage of its growth from the seedling in the nursery to the ripe ear. The worst pests are plant bugs, stem borers, army worms, and grasshoppers, of which each country has representative species. The greatest total damage is probably caused by paddy bugs, but the worst individual pest is frequently a stem borer or an army-worm. The importance of paddy pests, however, is frequently local as is only to be expected with a crop such as paddy, which is grown over a wide range of climatic conditions and under various cultural methods. Further, many paddy pests attack sporadically, so that an insignificant one may suddenly become important, or a once injurious insect may disappear.

The vast majority of paddy pests belong to the orders: Orthoptera (grasshoppers and locusts, which include the mole crickets), Hemiptera (plant bugs) which suck the sap, Lepidoptera (butterflies and moths) which include the stem borers, leaf rollers, case worms, cut worms, and army worms, and the Coleoptera (beetles) of which probably the root weevils occasion most damage to the crop. There are a few Diptera (true flies) of importance, mainly gallflies and fruit flies, and a very few Trichoptera (caddis flies) and Thysanoptera (thrips).

The varied habits of paddy pests are such that the plant can be attacked at every stage of growth—seedlings in the nursery bed by army worms, root caterpillars, and grasshoppers; young plants in the field by leaf-eating beetles, leafhopper bugs, leaf rollers, and case worms; stems by stem-boring caterpillars; flowers by gallflies and blister beetles which feed on pollen; and developing grain by earhead bugs.

But alarming as is this array of potential enemies—and several hundred species are known—most paddy-growing countries have

few really troublesome pests, though the damage occasioned by these may be considerable. It is comforting, too, to read the following opinion:*

> Although heavy damage can be done by insect pests and continuous cultivation of rice over wide areas seems to provide ideal conditions for their accumulation, no species is likely to become a serious threat to the existence of the rice industry in any land. Strongly acting against this are such factors as the hazards to insect life of alternate flooding and drying; the break in pest life histories caused by transplanting; pest dependence of special seasonal or other conditions for their most successful development and attack (e.g. early lack of rain for army worms and grasshoppers, proximity of shelter and alternate hosts for paddy bugs); high mortality among hibernating pests, including stem borers, by routine field cultural practices, and the high degree of hand control on the small paddy farms.

The plant bugs are probably the most widespread of all paddy pests; in Malaya, the Philippines, U.S.A., British Guiana, and Japan they are reported to be most serious. The genera *Leptocorisa*, *Scotinophara*, *Nezara*, and *Moridea* appear in swarms and suck the sap from the developing grain. *Leptocorisa acuta* Thünb is regarded throughout Asia as the most serious plant bug pest of paddy. Copeland[51] states that the damage it does varies from insignificant to complete destruction, and the loss of 5 to 25 per cent of the local crop is no rarity. Leafhoppers of *Nephotettix* and other genera also do great harm and cause dwarf disease. Attack by plant bugs is sporadic but can be devastating.

Among Lepidoptera, stem borers are major pests in each main paddy-growing area. In the old world, *Schoenobius bipunctifer*, the yellow stem borer, is probably the most important single pest of paddy, with *Chilo simplex*, the striped stem borer, running second. *Scirpophaga* sp. is the worst pest in Indonesia. *Proceras* spp. are among the chief borers in Malaya and in certain other regions in Asia. The damage caused by borers tends to be overestimated owing to the confusion of plant injury with crop yield, but can be very severe in sub-tropical and tropical areas where there is a build-up to five or six generations and there is overlapping of paddy crops throughout the year. It would not, perhaps, be an overstatement to say that borers annually cause about 2 per cent loss of rice yields in the main old-world rice regions. It would appear, therefore, that although other pests may be severe locally, stem borers are the most

* E. J. McNaughton, *World Paddy Pests* (Prelim. Report Commonwealth Institute of Entomology, Ref. C.1846, January 1946), to whom the author is indebted for much of the information in this chapter.

1. Paddy fields in the Po Valley, Italy

11. Paddy field Bandoeng, Java

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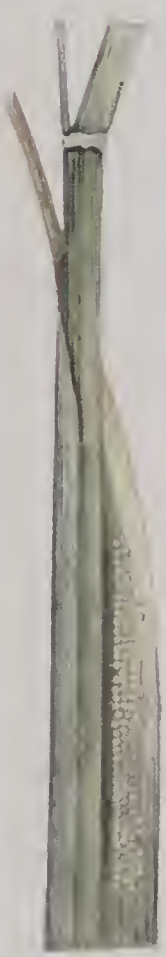

13

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13A

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11

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EXPLANATION OF PLATE III

1. *Proceras auricilia* Dudg., male
2. *Proceras auricilia* Dudg., female
3. Ova of *Proceras*
4. Larva of *Proceras*
5. Pupa of *Proceras*
6. *Schoenobius incertellus* Walk, female
7. Ova of *Schoenobius*
8. Larva of *Schoenobius*
9. Pupa of *Schoenobius*
10. Cocoon of *Schoenobius* in stem
11. *Sesamia inferens* Walk, male
12. *Sesamia inferens* Walk, female
13. Ova of *Sesamia* on inner surface of leaf-sheath which is laid back to expose them

13A. Ova of *Sesamia* enlarged

14. Larva of *Sesamia*
15. Pupa of *Sesamia* in leaf-sheath

With the exception of Figs 3, 4, 5, 8, 13 and 14 all figures slightly enlarged.
Fig. 3 enlarged 4.5

IV. Paddy Terraces in Northern Luzon, Philippines

consistently serious throughout all the important rice-producing regions in the world.

Among sporadic pests army worms rank high. *Spodoptera mauritia*, for instance, is stated to be the worst pest in south India, and is serious elsewhere. Other important genera are *Borolia*, *Laphygma*, *Prodenia*, and *Mocis*.

Case worms, i.e. caterpillars which make protective casings from leaves, do much damage by eating the foliage in nearly every paddy area. Cut worms are also destructive; they feed on the lower leaves and cut off plant stems at night, hiding in the soil by day. Ordinary leaf eaters, army worms, and leaf folders may also cause much damage. The principal genera are *Nymphula*, a case worm; the leaf folder *Cnaphalocrocis*; the ordinary leaf eater *Naranga*, and the army worm *Cirphis*.

Of the Coleoptera, leaf-mining weevils are serious in Asia. Occasional damage is caused by various root grubs, flea beetles, water weevils, and other beetles, but these are normally minor pests. In Arkansas water weevils in the larval stage have been known to reduce yields by as much as 30 per cent.

It is beyond the scope of the present book to treat of the life histories of paddy pests exhaustively. The more important and universal pests will, however, be briefly described in the following pages.

STEM BORERS

Stem borers are moth larvae which bore into the paddy stems shortly after hatching, and for most of their life remain in the stem, feeding on the tissues, and either killing or so injuring the plant that it produces little or no crop. These pests are mainly small moths of the family Pyralidae belonging to the genera *Schoenobius*, *Chilo*, *Scirpophaga*, *Proceras*, and the noctuid genus *Sesamia*.

The damage they do may be illustrated by the following examples. In Japan, *Schoenobius* is said to have caused a 2 per cent loss of the crop in 1933. In some districts of Kyushu (south Japan) there is reported to be a crop destruction of 50 to 60 per cent in four or five years out of ten, and of 20 to 40 per cent in the remaining five to six years, necessitating a reduction in land tax and sometimes driving farmers from home. The average annual loss in Formosa is estimated at 2 to 3 per cent of the crop; damage to the second crop is very severe and in certain localities infestation may reach 100 per cent and over half the crop be lost. In China, *Schoenobius* and *Chilo* are said to have caused an annual loss of 10 to 20 per cent. In India, *Schoenobius* in Konkan (Bombay) is said to cause a loss of crop

rarely less than 10 per cent and sometimes as large as 60 per cent. In the Philippines, *Scirpophaga innotata* destroyed or severely damaged 285,000 acres in 1927, and in 1935 attack was stated as "catastrophic." McNaughton states as his opinion that estimates such as these should be treated with circumspection, for the proportion of injured stems is not that of grain loss, as plants may recover owing to tillering, and furthermore because damage is subject to such local variations that estimates for large areas are largely guesswork. This view may be true, but the extensive damage is so evident that these and similar reports should not be underestimated. The subject is given prominence in this place because it points to the fact that the most severe damage appears to occur in areas where more than one annual crop of paddy is reaped, or where the overlapping of paddy crops permits the build-up of several broods of the pest in a year— a subject to which reference is made elsewhere in this book.

Fig. 6
Schoenobius bipunctifer (Walk).
Egg mass on leaf. × 5

Schoenobius bipunctifer, the yellow stem borer. The moths are nocturnal, hiding during the day under the upper leaf-sheaths. They become most active between 8 and 9 p.m. when they mate. The average length of life of the moth is five to seven days. No parasites of the moth are known, but they are preyed on by dragonflies, spiders, birds, and bats.

The eggs are laid in clusters on the underside of young paddy leaves about one to three inches from the tips and touching the mid-ribs. Each female contains 120 to 150 eggs and is responsible for two to five clusters. Large numbers of eggs are lost by natural enemies and dislodged by storms.

Three species of Hymenoptera, notably *Trichogramma* sp., a Chalcid fly, are said to parasitize from 20 to 60 per cent of the eggs in Formosa and 40 to 70 per cent in Japan. In Malaya, efforts have been made to control the pest by liberating *Trichogramma*[159] which also attacks *Proceras polychrysus* (Meyr.) and *Sesamia inferens* Walk., but after two years' work[52] it was considered to be an ineffective parasite even when liberated at the high rate of 1,300,000 per acre daily throughout the paddy season. Further, only *Proceras* was attacked to any extent, *Schoenobius* being immune owing to the hairy covering of the egg masses.

Normal incubation period is from six to seven days. The newly

hatched larvae wander about for a time and feed by scarifying the epidermis of the undersides of leaves, but soon make their way down to bore into the stems. Several larvae may enter the plant they are on, the others scatter to search for suitable hosts. This they do by suspending themselves from fine threads emitted from their mouths; they are also blown by wind, often for long distances, until another suitable plant is encountered. Some fall into the irrigation water and are thus carried for long distances before they find a host. At this scattering stage only 10 to 25 per cent of the larvae succeed in finding a host, the remainder perish.

If the larvae hatch on stemless seedlings in the nursery they soon run out of food and are forced to emerge and seek other host plants. They may find larger plants, but because it is customary to cut off the tops of seedlings before conveying them to the field for transplanting, and as injured seedlings are carefully discarded, there is little danger of transferring the pest from the nursery bed to the field.

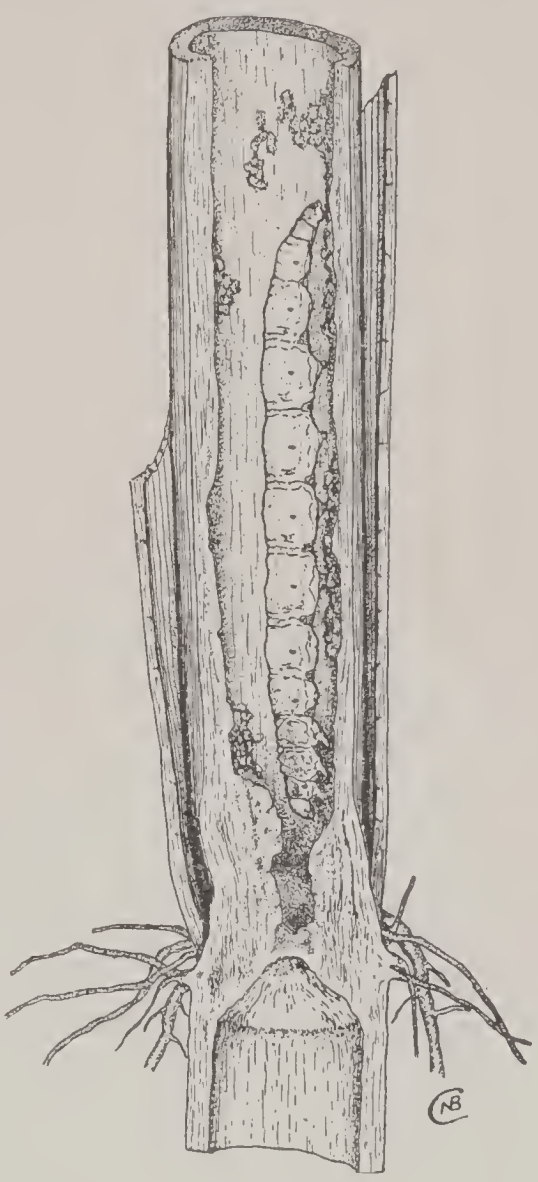


FIG. 7

Schoenobius bipunctifer (Walk). Larva in stem. × 2½

The larvae enter the stem immediately above the point where the leaf blade diverges from the leaf sheath. After eating the stem tissue of the uppermost internode the larva bores through the node to the internode below. When the stem is exhausted, the caterpillar migrates to another by floating in the water. A larva about to leave a stem crawls up to the leaf tip, bends the leaf margin with a thread, and makes a rolled portion into which it crawls and then severs it to fit the body length. In this protective covering, with head and thorax protruding, it either attacks a suitable stem on the same plant

or, suspending itself from the plant by a thread till it reaches the water surface, it then drifts about in its cover until it contacts a stem. In the course of its life each larva injures two or three stems.

As maturity approaches, the larva bores to the base of the stem where it pupates two or three inches under the soil level, well protected against water. When larvae pupate in flooded paddy-fields, the emergence hole is just above water level. Many larvae are not ready for pupation when the crop is harvested and may therefore be removed in the cut stems and die on drying out of the straw. Other larvae reach the stem bases but do not prepare for pupation and will pass through the dry season. This has been observed in Japan and China. Such hibernating larvae and pupae are liable to be destroyed by ploughing and irrigation for the next paddy crop.

Larvae are well equipped for protection under all conditions and parasitism is therefore small.

The pupal stage may last from six to fourteen days, when the moths emerge without difficulty. In irrigated fields they can emerge successfully through four or five inches of water, and submerged land can give rise to many moths unless flooding has been sufficiently prolonged to rot the stubble and destroy hibernating larvae. If stubble has merely been ploughed in, the moths can often break through the earth, though with difficulty. Ploughing plus submergence effectively prevents exit.

The number of generations per year depends on climate and on the continued presence of host plants. In Japan, where a single rice crop is the rule, there are two generations in the north and three in the south. In Formosa, where double cropping is the normal practice, there are four generations in the cooler northern half of the island and five to six in the tropical south. Probably two generations are characteristic in the northern limit of the pest's distribution and six in the tropics.

Perhaps the most effective method of controlling this pest is by ploughing the land immediately after the crop has been reaped, followed by submergence for as long a period as possible up to three months, and thus avoiding as far as possible any overlapping of paddy crops that would provide a continuity of host plants for the pest. It is appreciated that this is a counsel of perfection and in many areas other, and possibly less effective, means must be found to minimize damage. The moths are intensely phototropic and light traps are still widely used, though Japanese experience has shown that the proportion of moths caught is too small to reduce pest numbers appreciably in the succeeding generation. It has been observed in Malaya that males of *Schoenobius* are attracted to light

more than females in the proportion of roughly 2:1; with *Proceras* the reverse is the case. Hand collection of eggs and of injured plants can be effective, but is slow and costly. The herding of young ducks in the affected paddy-fields is a useful method of mopping up exposed larvae, but there is risk of damage to the crop. Burning the standing stubble is of little use as the larvae are below ground. The use of resistant varieties of paddy has met with no success. Dry-land paddy is not attacked because the stems are too hard for the pest to penetrate. Insecticides have been little used owing to the difficulty in contacting the larvae. In China, steeping tobacco stems in water at 132 to 264 lb. of stems per acre and keeping one to two inches of water in the field for two weeks afterwards is said to kill young larvae.

One is therefore driven to the conclusion that in the present stage of knowledge concerning the control of this and other stem borers, cultural methods offer the best chances of reducing crop losses.

Chilo suppressalis (Walk). *Chilo* is considered the most serious borer in the northern paddy areas of Asia, and occurs elsewhere on

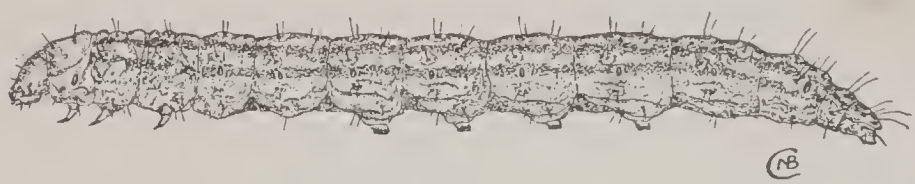


Fig. 8
Chilo suppressalis (Walk). Larva. × 4

this continent. It is said to be the worst individual paddy pest in Japan, is very serious in Korea, and occurs as far north as Manchuria.

In Japan the moths emerge mostly from mid-June and July for the first brood and from mid to late August for the second. Adult moths fly around seed beds until the seedlings are large enough for concealment. Oviposition begins within two or three days of emergence. Spring-brood eggs are usually laid in the seed bed near the borders, on the upper sides of leaves and from one to two inches from the tip. Summer-brood eggs are laid on the leaf-sheaths. Egg clusters are about five to six per moth with an average of fifty to sixty eggs per cluster. In four to twelve days the eggs hatch. The larval life is about thirty-six days for the first generation and 350 to 300 days for the hibernating generation. Pupation of the spring generation lasts two weeks and the summer generation about one week. Larvae of the spring generation disperse by silk threads. Young leaves are often injured at the top of the sheaths, break off, and float

on the water, especially after strong winds. A single larva will destroy ten or more plants as against only two or three by *Schoenobius*. Pupation occurs in the stem just above water level.

Summer larvae do not scatter after hatching but feed for about ten days on the plant upon which the eggs were laid. When the plant is dying, they migrate to neighbouring plants and usually one or two larvae enter each stem. They seldom migrate further than five feet. Attacked stems die without heading, and new heads die or, if attacked late, bear inferior grain.

At harvest, larvae are usually found four to seven inches above the soil surface, and as many as 80 per cent may be removed in the cut straw, though proportions vary greatly with conditions and as many may be left in the stubble. The larvae usually hibernate in stubble but, unlike *Schoenobius*, also migrate to the stems of various natural and cultivated grasses. Those removed in the cut paddy do not die but feed on the withered stems and when the paddy is stacked or stored after harvest leave the straw to enter grass stems. They migrate extensively in late spring to pupate among straw, rubbish, and in crevices, holes of about four millimetres diameter being preferred. Many form cocoons about four inches from the ends of cut straw. Those in stubble emerge and enter straw more exposed to the air.

Various methods of control have been used with success. Collecting eggs in the seed bed is important because the larvae can migrate to the field through host plants. Light trapping helps to reduce numbers, although the pest is less phototropic than *Schoenobius*. Cutting out infested stems before the larvae have scattered gives marked control of the summer generation. Flooding young paddy to a depth of four to six inches for a day is effective, and complete submergence by bending the plants and forcing them under the water gives 80 to 90 per cent kill. Stubble submergence for three weeks gives excellent control in Java. In China an oil film on the water is recommended to destroy larvae of *Chilo* and *Sesamia*. Other control measures are adopted as described for *Schoenobius*.

It is desirable to destroy the pest removed in the straw. The larvae can be trapped by mixing in with the paddy straw strong stems of maize or sorghum into which they will migrate. The introduced stems should then be removed and burnt. Fumigation of straw with carbon bisulphide is effective, but chloropicrin is said to be better for this purpose, using 1 lb. to 1,000 cu. ft. exposed for two days.

Proceras polychrysus (Meyr.) This is a most serious pest of paddy in Malaya, particularly as no really effective method of control has yet been discovered.

The moth lays eggs on both the upper and under sides of the leaves, an average of 400 eggs being laid per female. The eggs hatch in four to seven days and the larva enters the top of the leaf sheath and works towards the base, boring into the stem. Larvae may be found in stems up to one foot above water level; they can live in damp stubble and have alternative hosts in grasses. The larva reaches maturity in about one month when it pupates inside the stem and sometimes between the leaf-sheath and the stem. The pupal stage lasts from four to twelve days, when the moth emerges and may live for three to twelve days.

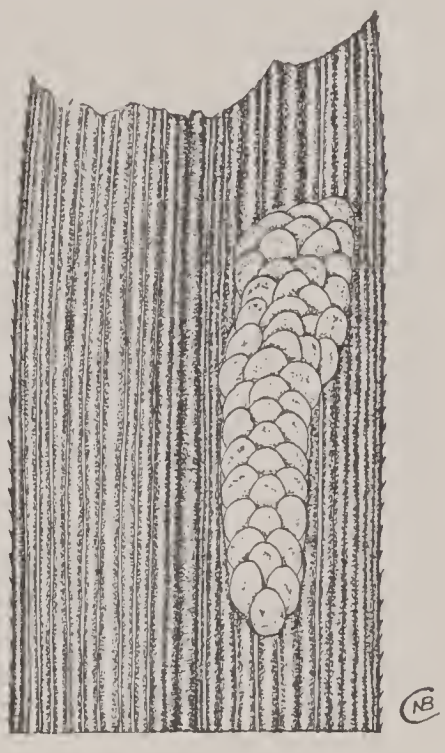


FIG. 9
Proceras polychrysus (Meyr.). Egg mass on leaf. × 5

Light trapping for the control of this pest is unsatisfactory; it cannot be controlled by flooding, and liberating predators in large numbers in affected areas has proved to be unsatisfactory.

Control measures appear to be equally ineffective against *Sesamia inferens* Walk., the Violet Stem Borer, a noctuid moth common throughout the paddy areas in Asia, the larvae of which bore into the stems. The pest is particularly difficult to control because it has a large number of alternative host-plants, the eggs being laid where the encircling margins of the leaf-sheath meet are thereby well protected, and the larvae can live within submerged stems.

Scirpophaga innotata, the White Stem Borer, is by far the worst pest of paddy in Indonesia, but is unimportant elsewhere. Adjustment of sowing and transplanting times, flooding, and crop rotation

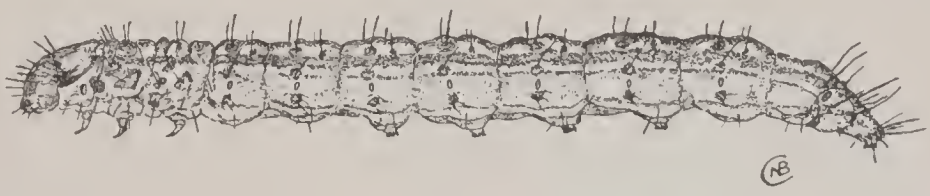


FIG. 10
Proceras polychrysus (Meyr.). Larva. × 3

are standard control methods. Van der Laan[288] indicates the possibilities of control by spraying seed beds with 0·04 per cent D.D.T. emulsion at thirteen and twenty days after sowing. This resulted in a reduction of 25 to 30 per cent. He used a power-driven mist blower.

This seems to be viewed as a practical proposition for the future. Other insecticides were also tried, including Toxaphene, Parathion, and derris.

Elasmopalpus lignosellus is a Brazilian pest of upland paddy. Its larvae bore into the stems at or below ground level, each destroying about four plants.

LEAF CATERPILLARS

Compared with stem borers and paddy bugs, leaf caterpillars are not of great importance, although sporadic attacks of army worms can entirely destroy nurseries of paddy plants and fields of broadcasted paddy.

The most widely spread army worm is probably *Spodoptera mauritia*, which appears when the paddy seed is germinating. It occurs in south India, Ceylon, Java, Malaya, and the Oriental tropic

FIG. 11

Spodoptera mauritia (Borsd.). Larva. × 2½

and Pacific area generally, and is claimed to be the most important pest of south India, where broadcasting in place of transplanting is very common.

Seedlings in wet nurseries up to about twenty days old and broadcast sowing in ill-drained places are selected for oviposition. Plants over twenty days old and dry fields are not attacked. It is characteristic of moths to appear in large numbers leading to heavy infestation of extensive areas of newly sown paddy.

The eggs are laid on the leaves and hatch in four to five days. The newly hatched larvae scrape green matter from the leaf tips and rest within the rolled edges of tender shoots. They let themselves down by silken threads and are so wafted to other plants, but they can crawl to plants should they fall to the ground. As the larvae develop they feed only at night unless the weather is cloudy, hiding in cracks in the soil by day. The larvae migrate from field to field doing extensive damage to the crop. In about four weeks' time, when full grown, the larvae pupate in damp or moist soil.

The larvae thrive on various grasses. They suffer severely from

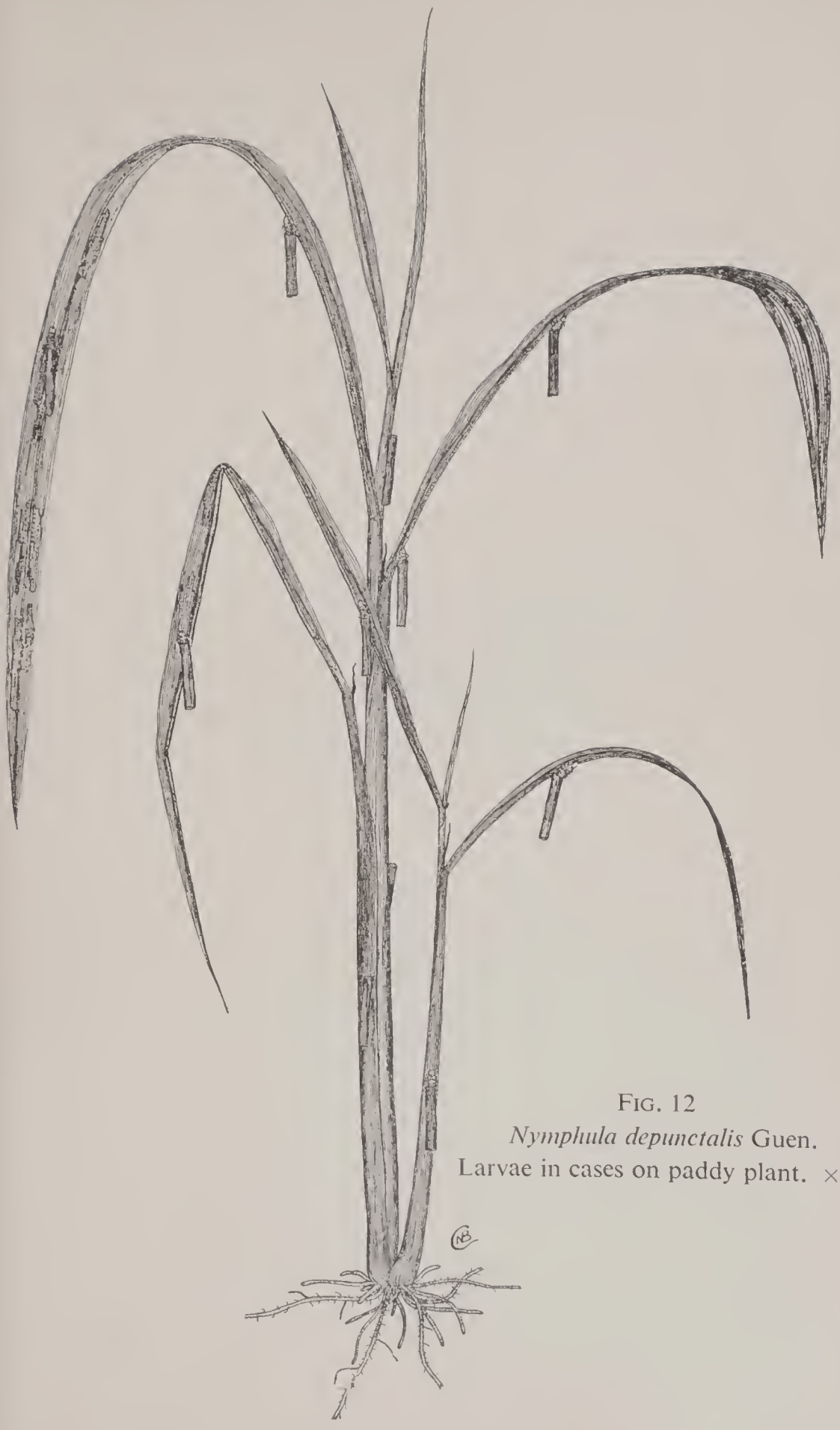


FIG. 12
Nymphula depunctalis Guen.
Larvae in cases on paddy plant. × ½

heavy rains at all stages, are prone to bacterial disease, are attacked by several parasites, and are eaten by birds.

So sudden and unexpected are attacks of army caterpillars as a rule that the cultivator is unaware of the danger before his crop is entirely destroyed. Where this happens to the nursery, it entails replanting with a variety of paddy of shorter maturation period to make up for the delay.

Control measures include the flooding of the nursery bed for two or three days where this is practicable. Attack is said to be less severe if the land is kept dry for a fortnight after sowing, but such a procedure will militate against a good crop. Standing water kills the larvae, and a film of kerosene on the flooded field hastens their

FIG. 13

Nymphula depunctalis Guen. Adult. × 7

death. Moving swarms can be kept away from the fields by trenching. Ducks rapidly clear up the larvae. Dusting with a 1 : 8 calcium arsenate and lime dust has been successful in India. An arsenical bait is used in Fiji. A 5 per cent D.D.T. dust is said to be completely effective.

Several other army worms are important. *Borolia venalba* is common in Ceylon and India. The larvae web two or three leaves together to make a shelter within which they spin cocoons and pupate. Control measures are similar to those described for *Spodoptera*, but collecting and destroying cocoons is also useful. Wasp and fly parasites assist in keeping the pest in check. *Laphygma frugiperda* is a serious pest in British Guiana and is also known in the United States and the Far East. Flooding the nursery beds is recommended, but is not always possible. In Formosa, the cut worm *Prodenia*

litura is controlled by lead arsenate, but derris and contact sprays are ineffective. In Brazil, *Mocis* (*Remegia*) *repanda* sometimes appears in large numbers in rain after a long dry spell and completely destroys whole fields. Collection of larvae, and dusting with lead arsenate, are methods used for its control.

Naranga aenescens Moore is serious in parts of China, and in Korea there are outbreaks every four or five years. The larvae feed voraciously and build cases which, when cut from the plant, fall into the water and float. Four or five broods are produced in the year, and pupation is completed by early October. Spraying with lead arsenate is employed in Korea, and in China tobacco dust is said to be effective. *Nymphula depunctalis* is important in Malaya, the Philippines, and Lower Burma, attacking the seed beds and young plants in the field. Its larvae are semi-aquatic and can withstand prolonged immersion. They depend entirely on water for their oxygen supply. They carry their water supply about with them and when the dissolved oxygen has been used up they descend to the surface of the water and, by violent contraction and elongation of the body, plus lateral flexure when fully extended, expel the water from their case and draw in a new supply. If the water can be drained off for a period they die from lack of oxygen. Therefore, they cannot attack nurseries unless these are in water. In the case of *depunctalis* Guen. the larvae, at least in confinement, feed on the lower side of paddy leaves which are lying flat on the water, or on submerged portions of a leaf, for the first week to ten days. Only then do they make their cases. Pupation may take place below water, but more usually above water. Moths emerge with ease from below water. In the case of *fluctuosalis* Zell. the young larvae move about quite actively about $1\frac{1}{2}$ inches below the surface, crawling on the bottom, on the base of the paddy stems, and they also drift freely, but always below water.* Control is by dislodging leaf cases by means of ropes, draining off the water and collecting the cases. A kerosene film on the water helps to kill, and in India a 1 : 3 dust of paris green and wood ash has been used. *Nymphula vittalis*, which is a pest in Japan and Korea, has been controlled by dusting calcium cyanamide and by destroying the stubble in which the larvae hibernate.

Of leaf folders, a Pyralid moth, *Cnaphalocrocis medinalis* Guen., is said to cause over 5 per cent loss in Tonkin, a 10 per cent loss in South Travancore, and up to 60 per cent loss in dry seasons in Madagascar. Its larvae cut and fold leaves and also bore stems. Deep flooding is recommended to combat this pest. In India, fertilizers are said to help the plants to recover. In Korea, lead arsenate is

* From a private communication from Mr. H. T. Pagden.

recommended. *Parnara guttatus* Bremer and Grey, synonymous *P. bada* Moore, is a leaf folder serious in Kwangsi. It is controlled by the use of special combs for gathering larvae from the leaves, by knocking larvae into oiled irrigation water, and by the application of tobacco-lime dust. In Japan, lead arsenate-Bordeaux mixture is found to be effective. *Pelopidas mathias* (F) is equally common as *P. guttatus* in Malaya and has similar habits.

Cut worms include *Crambus malacellus* in Mauritius, and the army worms *Cirphis unipuncta* Haw, an almost universal pest. The former has been controlled by watering Cyanogas on to the soil in the proportion of 2 grammes Cyanogas to 1 litre of water and applying 6 litres of the solution to 10 sq. ft. The latter pest has been controlled with poison baits.

PADDY BUGS

Paddy bugs are serious pests in most countries, some attacking the grain during development, others feeding on the young leaves. They are capable of producing many generations in a season and under favourable conditions can therefore do extensive damage.

Coreid Bugs

Leptocorisa acuta Thnbg. is widely distributed throughout the East and Australia, and is generally recognized as the most serious of the bug pests of paddy. In the Pacific it is replaced by *L. varicornis* F. It lives and breeds on various grasses, but appears to prefer paddy, for it attacks the crop in swarms, sucking the sap from the developing grain. Awned varieties of paddy are not attacked. Attack continues until the rice grain hardens. The bugs then migrate to shady places and remain inactive throughout the dry months.

The female lays about 200 eggs at a rate of about twenty a day, glueing them in regular rows usually on the upper side of the paddy leaves close to the mid-rib. The nymphs emerge in about a week and after sucking the leaf sap for about two days, climb into the panicles and feed on the milk-ripe grain, sucking the contents until only the empty seed coat remains. The bugs feed all day but are particularly active in the morning and evening. If disturbed, the adults fly (young bugs are wingless) for short distances and again settle on the developing panicles. They are easily caught in the early morning when their wings are damp.

Various methods are employed to keep the pest in check. The best precaution is to keep the bunds and banks in the vicinity of the fields as clean as possible between growing seasons in order to deny to the pest the wild grasses which are its alternative hosts when no growing

paddy is at hand. This measure applies also to most of the other paddy bugs. Uniformity of planting to avoid extending the growing season is strongly recommended—but how difficult to put into practice! In Malaya, large bags, coated on the inside with crude oil emulsion, are swept over the growing crop. Netting the insects is also employed and carrion bait are also at present much in use. In India and Ceylon rice winnow baskets are used, smeared inside with a sticky preparation made by heating a mixture of breadfruit latex, coconut oil, and a small quantity of powdered resin. Egg collection and shaking the nymphs into water on which there is a film of kerosene are also useful methods of control. The pest has no serious natural enemies, but about 25 per cent of the eggs are infected by parasites.

PENTATOMID BUGS (Shield Bugs)

The life history of these pests and methods of control are similar to those of *Leptocorisa*. *Scotinophara lurida* is controlled in China by flooding to a depth of five inches every fourth day, allowing the water to stand for one day. In Ceylon, the bugs are shaken into a film of kerosene oil, the water being run off after three to five hours.

Scotinophara coarctata,[53] the Black Bug of Paddy, does considerable damage in Malaya by sucking the sap from the stems, as a result of which the panicles do not develop. In severe attacks the plants are stunted, the leaves become reddish-brown, and few plants form panicles. The nymphs and adults seem free from natural enemies, probably on account of their "stink" glands. The eggs, when not protected by the body of the female, are attacked by a Chalcidoid parasite. Control as for *Leptocorisa*. When irrigation is practised, the affected area may be flooded and the nymphs and adults skimmed off. Spraying with kerosene emulsion or derris has proved successful, but may not be economic. D.D.T. and B.H.C. dusts are very effective, particularly applied from a power duster, and insecticidal fogs containing these may be useful.

Moridea poecilia is well known in British Guiana, and in Uruguay a *Moridea* sp. is also well known and is controlled by means of a 1·6 per cent nicotine sulphate spray and kerosene emulsion. *Nezara viridula* is almost cosmopolitan. In New South Wales, where it is a serious pest also on beans and tomatoes, fair control has been gained with pyrethrum dust alone or in equal parts with 2·5 per cent nicotine dust applied with a dust gun. *Solubea pugnax* is a pest in the United States. The bugs may consume the entire contents of the kernels in the milk stage, so that grain is not produced. When kernels in the dough stage are attacked, portions of the contents are extracted,

leaving a chalky discoloured area. Kernels so affected are called "pecky rice." Moulds often enter the punctures causing black specks, and kernels so affected often break in milling. Late-maturing varieties appear to be most severely attacked. Cold winters cause a high mortality and limit pest incidence. No chemical control measures are taken.

FIG. 14
Sogata furcifera (Horv.). Adult female. × 7

JASSID BUGS (Leaf Hoppers)

Nephotettix spp. are serious and widespread in Asia, East Africa, and Europe. In Japan, *N. bipunctatus cincticeps* Uhl. has proved to be a vector of the virus causing dwarf disease of rice. In India, *N. bipunctatus* is said to have caused damage amounting to £1,000,000 in one division of the Central Provinces. The pest may appear in swarms—as many as 150 hoppers may be seen on one leaf. The adults feed on the leaves by night and hide by day. Control measures

include early planting, sweeping the seed beds, and shaking the pest into water covered with a kerosene film. In the Philippines control has been gained by weekly applications of a solution of 2 lb. soft soap in 25 gallons of water; light traps are carried through the fields while a second man beats; weeding and use of fertilizers to stimulate growth are helpful.

Sogata furcifera (Horv.), which is severe in Japan, Formosa, Malaya, and Fiji, can be controlled by a derris spray.

Fulgoroid Bugs

Nilaparvata oryzae, which is one of the worst bugs in Formosa, attacks the lower part of the plant, nymphs and adults boring into the leaf sheaths. Good results have been obtained by spraying with petroleum oil with or without pyrethrum and by pyrethrum-soap sprays or, if there is no irrigation, by the use of tobacco dust. *Nisia atrovenosa* is prevalent in the Far East. It over-winters in the egg stage on paddy and grasses and is controlled by flooding, ploughing, and grass burning to destroy the hibernating egg masses. Tobacco dust kills the pest.

Coccid Bugs

Ripersia oryzae sucks the stem sap. In south India the pest can be so numerous that the ears are smothered and unable to emerge from the leaf-sheaths. Alternative hosts are grasses and sedges. Resistant varieties have been found which suffer 70 to 80 per cent less infestation than other varieties.

LEAF BEETLES

Hispa armigera is a Chrysomelid beetle common in India and South-east Asia, causing severe injury by mining the leaves. The young larvae mine the leaves, four to seven in a leaf, eating the green matter and causing the foliage to wither. The pest multiplies rapidly and may cause considerable damage to the crop. It also breeds on grasses, which makes control difficult. Netting the beetles is helpful. In Formosa it has been found that the larvae emerge from the leaf mines between 4 and 6 p.m. and crawl to other parts of the leaf or to fresh leaves. During this period netting is most effective. Adults can be collected in the evening, or sprayed with nicotine sulphate. Pyrethrum dusts and sprays are effective. Fields may also be drained and the adults sprayed with kerosene emulsion containing pyrethrum extract.

Hispa aenescens destroys seedlings and young paddy in India;

some control is possible by light trapping. *Hispa similis* is peculiar to Formosa and is controlled by burning grass where it hibernates, by hand collection, and by spraying nicotine sulphate or pyrethrum with soap.

Lema oryzae, the Rice Leaf Beetle, damages crops in Japan. *Lema flaviceps* causes severe damage to paddy-leaves in Korea.

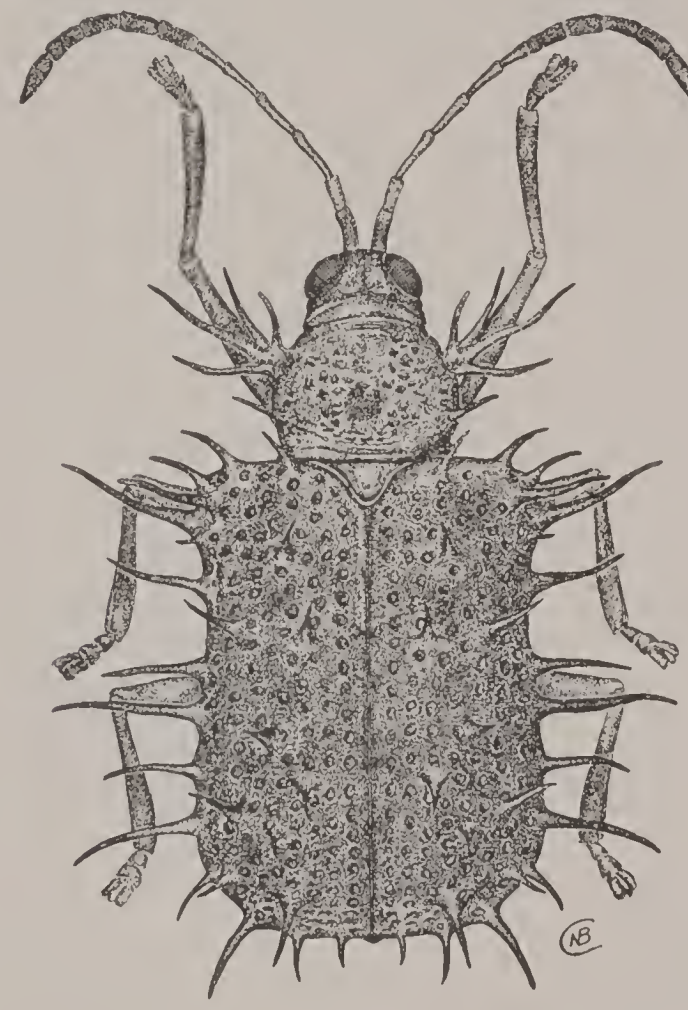


FIG. 15
Hispa armigera (Olev.). Adult. × 17

Control by hand collection of eggs and adults and spraying with lead arsenate. *Tricispa serica* is controlled in Madagascar by immersing seedling tops for fifteen to twenty seconds in boiling water before transplanting. This treatment does not harm the plants.

GRASSHOPPERS

Many species of grasshopper attack paddy, as well as grasses and other plants, but are not usually very serious.

Hieroglyphus banian (F) is injurious to paddy in India. Control is by ploughing and harrowing after harvest and by hand-digging of bunds to destroy the eggs. Hoppers in young paddy are netted, and the half-grown and adults are driven into a corner of the field and beaten to death. *Oxya velox* can cause severe damage to the crop in Korea when the pest is favoured with high temperature and little rain. It is also reported from the Solomons and from Malaya. In the latter region the commonest species on paddy is *O. chinensis* Thnbg. In Japan, when the fields are flooded to prepare for the transplanting, the eggs of *O. velox* float and are collected. In dry fields, a tobacco-lime dust is used. Migratory locusts rarely cause total destruction of the paddy crop. Trouble of this nature was experienced in Malaya for two or three years about 1914. The swarms were wiped out by systematic poisoning of the grass eaten by the pest in the hopper stage, aided by the nature of the country, which was unsuitable for swarming.

ROOT AND MISCELLANEOUS INSECT PESTS

Tipula spp., Leather Jackets. In Japan, *T. aino* is important, frequenting wet places, where it lays eggs on moist soil rich in organic matter. The larvae feed on decayed vegetable matter and in the roots of paddy and weeds. Control methods consist in attracting adults to lamps, and by killing the larvae by spraying the soil surface with petroleum emulsion with or without pyrethrum. Cyanide is also successful for this purpose. *T. conjugata* causes serious damage in the Russian Far East. Over-wintering larvae migrate from the peat bogs to paddy-fields and eat both roots and stems. Control methods are to drain the swamps if possible; larvae are killed by applying to the paddy-fields sodium arsenate or tobacco extract, using 1 oz. of the former or 4 oz. of the latter in 25 gallons of water.

Gryllotalpa spp., the Mole Cricket, is controlled in some regions by burying poison bait containing paris green or barium fluosilicate. A gall midge, *Pachdiplosis oryzae*, attacks the growing portions of young plants, causing "silvery shoots." The irritation results in the formation of galls instead of ear-bearing stems. Control is by use of early varieties, early transplanting, and fertilizer application to stimulate tillering. Light traps are useful. *Cecidomyia oryzae*, another gall midge, is similar and can cause up to 50 per cent loss of crop in India. *Atherigona oryzae* Mall., a paddy seedling fly common in dry paddy cultivation in Ceylon, Malaya, and Indonesia, and elsewhere in Asia, lays its eggs under the leaves. Maggots penetrate the leaf-sheath and bore down, killing the central shoot. It is con-

trolled in Java by flooding. *Chironomus oryzae* Mats. is common in Japan. It has been found on seedlings grown in a "wet" nursery in Malaya.

Thrips oryzae, Rice Thrips, is a sporadic pest, injuring seedlings in Italy, India, and south Asia. It sucks the sap from the leaves, causing wilting and often the death of the plant. The pest appears only when rains are delayed and is quickly checked when they come. Control by flooding for a few hours with a film of oil on the water, and knocking the pests into water by dragging with a rope. Use may be made of petroleum emulsions and nicotine emulsions. In south India good results have been obtained by applying to seed beds a spray made by steeping 5 lb. tobacco for 25 hours in 5 gallons of water, diluted to 1 : 6 for spraying.

OTHER PESTS

Crabs

In most tropical countries sea and land crabs are responsible for much damage to paddy by feeding on the seedlings and by burrowing into the bunds, thereby interfering with the irrigation.

Sea crabs, which breed in the sea, frequent paddy-fields of the coastal areas. In Burma, the adults go down to the sea, never to return, about the end of July, so that in areas where they are common, transplanting is postponed till their departure. A fresh lot of young crabs comes from the sea about the end of August, but the paddy plants are too large by this time for the young crabs to damage.

Land crabs are more destructive, because there is no migration, and they are liable to attack paddy in the nursery and newly transplanted paddy. They feed mostly by night and move more freely in water than on land. A common method of control adopted throughout the East is by trapping in wide-mouthed earthenware pots, known as *chattis*. The pots are buried with their rims about two inches above the level of the water, and baited with well-fried bran, moistened and made into large lumps. The bait remains effective for about two or three days, even if the pot becomes filled with water. Four or five pots are said to be effective in controlling a smallholding in a few days. Another method of control consists in mixing 3 to 4 lb. slaked lime with 3 to 4 gallons of water, adding $\frac{1}{2}$ to 1 pint of crude oil and 1 oz. of arsenical "white ant" powder, and pouring one or two cigarette tins of this mixture down each active crab hole, which is then blocked. The treatment is repeated at least once a month, and if persisted in, can almost clear an area of the

pest. Natural enemies of land crabs are rats and various birds of prey and water fowl. Ducks are useful in helping to effect control.

Birds

Birds can cause a heavy loss of grain in the field, especially where the crop is confined to a strip, e.g. along the banks of a river, and where there is plenty of adjacent cover. Sparrows, which are almost everywhere common, and in the East the rice bird with its conspicuously white head, are the worst offenders. In California, large flocks of blackbirds pick up the broadcasted seed before it is irrigated, and wild duck often cause serious damage. Mud hens alight in the open water after seeding and feed upon the soaked seed paddy. Migratory ducks are reported to swarm at times in the paddy-fields, when they may do much harm.

Measures against birds vary according to the species, but in general scaring is probably the most effective, especially for the smaller types of birds. Ingenious scares are devised by Asiatics, the aim being to protect the greatest possible area with the least possible trouble. Many of these scares are automatic, making use of water and wind power. A kite, resembling a hawk, is said to be a good scare for small birds. Netting is sometimes used against swarming birds. Pieces of bright tin, flashing in the sunlight, undoubtedly scare birds for a time: thin tin is best as it also rattles in the wind.

Rats

Rats are very destructive both to paddy and rice; they gnaw the stems, eat the standing grain, and ravage the rice store. The damage they do has been variously estimated at 5 to even 10 per cent of the crop—pure guesswork—but whatever the figure may be, the outstanding fact remains that they are a serious menace.

Once the crop is stored it ought to be safe, for rat-proofing a building is simple. But how few stores does one find that are proofed! Rats in the field, however, are more difficult to control, in fact, any relaxation of effort leads to immediate increase in their number. Individual losses are less if dates of cultivation are so arranged that all the crop is ripe at the same time. The rat population depends on the amount of food available; therefore, the longer the period over which harvesting extends, the greater the rat population. It is generally recommended that waste land in the vicinity of the fields should be kept clear of undergrowth which provides refuge for rodents. Desirable as this may be, it is unlikely to be widely practised. One must, therefore, rely on direct methods of dealing with this pest, and of these poison baits are the most suc-

cessful. But even with poison baits it is essential for success that the campaign should cover as wide an area as possible, otherwise the rat population will migrate from the untreated area to the treated area where there is less rat competition for the available food.

It has been found that if a poisoned bait is offered to rats, they are suspicious of it and nibble at it first. They therefore eat a sub-lethal dose of the poison, enough to make them shy of the bait in future. It is therefore necessary to offer them an unpoisoned bait in the first instance, and when they have confidence to consume the bait, the poison is introduced. Changes of bait must be made from time to time, as the rats learn to avoid a bait that contains poison.

Several poisons are suitable for rat baits. The three standard poisons[158] are zinc phosphide, the most deadly and the most popular because it kills very quickly and leaves many dead rats in the open; finely powdered arsenic (arsenious oxide); and thirdly, red squill, prepared from a large bulb (*Urginea Maritima*) grown in North Africa and the Mediterranean area.

Sodium arsenate and barium carbonate have both been used for systematic destruction of rats on paddy-fields. A most successful bait consists of sodium arsenate one part by volume, rice polishings four parts, and dried fish or prawn "dust" one part by volume. Coconut or palm oil is used to bind the mixture into little balls. The balls are easily dissolved in rain and are therefore put inside short lengths of bamboo to protect them. This also makes them inaccessible to most domestic animals and to children. Inserting this poison into the body of a grasshopper or dragonfly makes the bait irresistible to rats. Barium carbonate baits can be prepared in the same way.

Other poisons have been recommended[20] for rat destruction: arsenious oxide in the proportion of 10 per cent by weight, or 15 per cent in the dry base; alpha-naphthyl-thio-urea (A.N.T.U.) in the proportion of 2 per cent by weight; red squill powder. Red squill is, however, uncertain in its action, and A.N.T.U. kills the brown rat, but not the black rat.

Much has been heard from time to time on the use of bacterial cultures for the destruction of rats. Results have been variable, and there is no evidence that these cultures have ever been successful.

NEW INSECTICIDES

In recent years new and potent insecticides have been evolved, such as D.D.T., Gamma B.H.C., Chlordan, Aldrin, Dieldrin, Toxaphene, Parathion, O.M.P.A., Isopestox, T.E.P.P., to mention but a

few, and a number of proprietary products containing one or another of these and other substances are now on the market.

Little is yet known of the value of these insecticides against paddy pests, and it will require a great deal of careful experiment in the field to determine their real value. Baptist[19] states that D.D.T. and Gamma B.H.C. show promise with regard to the majority of serious economic pests in Ceylon. Experiments elsewhere seem to confirm this view, but as Baptist points out, the potency of these insecticides makes them equally effective against beneficial insects, and a large number of crop pests are normally kept at negligible population levels through the activities of insect parasites and predators. Indiscriminate use of these insecticides may, therefore, lead to all sorts of complications.

Chapter VII

DISEASES

*Importance of Diseases—Diseases of the Foliage—Diseases of the Stem and Leaf Sheath—Seedling Blights and Foot Rot—Diseases of the Grain and Inflorescence—Diseases caused by Nematodes—Diseases caused by Unfavourable Soil Conditions—Deficiency Diseases—Virus Diseases.**

IMPORTANCE OF DISEASES

General recognition has been accorded to the importance of insect pests of paddy, the damage they do is widespread and very evident, but the loss of crop due to diseases is often overlooked, or considered as negligible. In many countries this may be true, but it is also true that the crop is liable to many diseases any one of which may suddenly occasion widespread damage. Padwick[178] states that it is difficult to estimate the part that disease plays in the economy of rice production, but points to the fact that diseases such as "brusone," blast, brown leaf spot, "ufra," seedling blight, and dwarf disease, to mention only a few, have from time to time caused great damage. "The most serious form of loss," he continues, "is the epiphytotic, even though on the average it may cause losses of only 5 or 10 per cent in yield." Brown spot disease was held to have been the major factor contributing to the Bengal famine in 1942, and a blast epidemic was responsible for famine conditions in parts of Japan in 1941. The urgent necessity of increasing the production of rice by all means, which has been emphasized by the Food and Agriculture Organization of the United Nations, directs attention anew to the part played by diseases in lowering yield. Knowledge of the diseases and early diagnosis may obviate preventable losses, while in the early treatment of disease, and indeed in its prevention, improved cultural methods and better water control will be found to be of paramount importance.

* The above classification is that adopted by Dr. G. Watts Padwick in his book *Manual of Rice Diseases*. In the preparation of this chapter free use has been made of the information contained in Dr. Padwick's book, and also of *Diseases of Field Crops*, by J. G. Dickson.

DISEASES OF THE FOLIAGE

BLAST. Rotten Neck, "Brusone"?, *Piricularia oryzae* Cav.

The name Brusone has been applied to a number of damaging influences of quite different character which cause outwardly similar

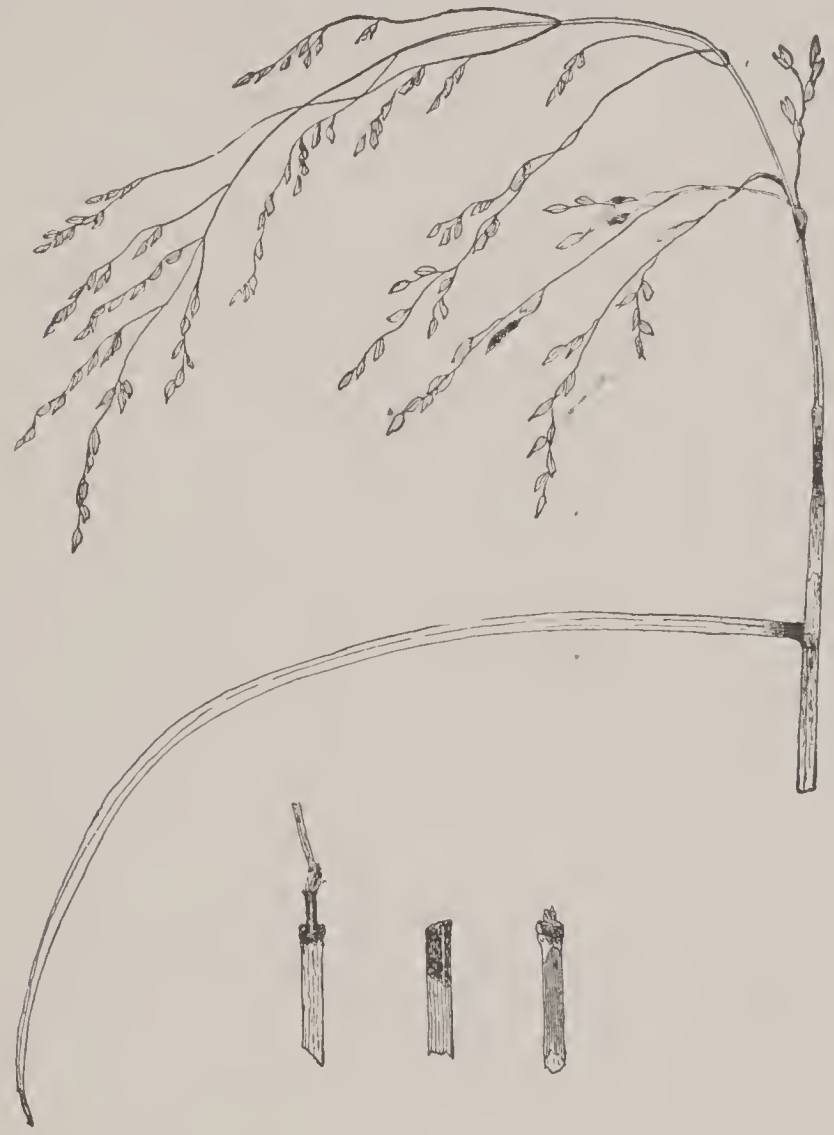


Fig. 16

Blast, *Piricularia oryzae*

Above: Spore masses at the base of the leaf, on the culm, rachids, and glumes.

Below: Nodes blackened by the fungus. × ½

symptoms. According to Winkler[273] the many different phenomena of the disease have led to a great number of names for it, and the fungi which are said to be connected with the disease are probably for the greater part only different stages of the development of one

large polymorphous class which include *Piricularia oryzae*, *P. grisea*, *Helminthosporum oryzae*, *Cladosporium* sp., and others. The fungus *Piricularia oryzae* Cavara has come to be accepted as the cause of "blast," or rotten-neck disease of paddy, which many workers, rather uncritically, accepted as being synonymous with "brusone."

The disease has long been known and feared, and is widely distributed. Spore germination and conidial production are dependent upon high relative humidity; it is therefore more serious in most of the humid paddy areas of the world; paddy grown under irrigation in regions of low relative humidity, as in California, is not damaged by the disease.

The symptoms of the disease are usually found on the leaves, but it also occurs on the culms, branches of the panicle, and floral structures. On the leaves the disease is first seen as small, bluish flecks which develop to brown spots with ash-grey centres. The spots increase and merge until the leaf is brown and shrivelled. Spots on the leaf-sheath resemble those on the leaf. "Rotten neck," i.e. lesions on the neck of the culm and on the panicle branches near the base of the panicle, is a conspicuous symptom. If the plants are attacked early there is no filling-out of the grains and the panicle therefore remains erect, but if the infection occurs when some of the grains have already filled, the panicles drop over, giving rise to the name "rotten neck." In very severe attacks the heads may emerge from the sheaths but become completely whitened long before the normal time of ripening. Externally, the appearance may be indistinguishable from borer attack, but instead of the reddish-brown discoloration of the enclosed culm, a grey, fluffy mycelium will be found, and the stem is shrivelled.

The disease may be carried in infected seed, and the fungus has been found within the tissues of the embryo, endosperm, bran layers, and glumes, and between the glume and the kernel. It may also be spread by airborne spores, and can over-winter as conidia or mycelium.

There are considerable differences in the susceptibility of paddy varieties to the disease, as well as of paddy growing under varying soil conditions. The disease is said to be worst on land newly planted to paddy, and seedlings grown in a wet nursery are more resistant than are those raised in a dry nursery. Susceptibility also varies in inverse ratio to the amount of water contained in the soil; green manures favour development, whereas superphosphate is beneficial. Excessive applications of nitrogen intensify blast, but potash may partly counteract this excessive nitrogen effect. Early-maturing varieties tend to have a lower infection. Mechanical injury, such, for instance, as may result from high winds, favours infection.

While no variety of paddy appears to be immune to blast, many show a high degree of resistance, although, in some cases, resistant varieties appear to deteriorate in this respect. The most resistant are those having a reclining shot-blade, long ear emergence, and a spreading panicle. The resistance of varieties is found to be associated with cell-wall composition and tissue anatomy.

No one method of control will ensure freedom from the disease. It is suggested that growing the seedlings in a wet nursery, flooding the land and maintaining the irrigation water on the land as soon as the disease is discovered may prove effective. Straw and stubble from a diseased crop should be burnt. The use of seed from a diseased crop should be avoided, and suspected seed treated with a mercurial seed dressing. Manurial and cultural practices likely to result in excessive vegetative growth should be avoided. Resistant varieties should be grown, or those that mature early, varieties selected having a reclining shot-blade, long ear emergence, and a spreading panicle. It is claimed that the fungus may be controlled by spraying with Bordeaux mixture just before the emergence of the earheads.

FIG. 17

Brown spot, *Cochliobolus miyabeanus*. Kernels and leaf spotted and blackened with conidiospores and spores. × ½

BROWN SPOT (Sesame leaf spot). *Cochliobolus miyabeanus* = *Helminthosporium oryzae* Breda de Haan.

Brown spot disease is world-wide in distribution and may cause considerable damage to the paddy in the nursery, to the plants in the field, or in the quality and yield of grain. Losses in the nursery, probably caused by planting infected seed, may cause irregular germination, but the greatest damage is usually when the seedling leaves and culms are infected. The plants may survive, but in a weakened condition, resulting in shrivelling and poor setting of the grain. Kernel infection may amount to the blackening of small areas of the glumes, or may affect the entire glume.

The symptoms of the disease occur in the coleoptile, the leaf, leaf-sheath, and glume. On the coleoptile the spots are brown, small, and circular to oval. On the leaves and leaf-sheath they vary in size and shape from minute dots to circular, eye-shaped, or oval spots. On the glumes, the disease appears as black spots, or in severe attack the entire surface of the glumes may be coated with a dark brown, velvety mat of sporophores and spores.

Knowledge of control measures is incomplete and inadequate to ensure freedom. Stubble of infected crops should be burnt, as should also possible alternative hosts, and the passage of irrigation water from an infected to a healthy crop should, if possible, be avoided.

FIG. 18

Brown spot, *Cochliobolus miyabeanus*. Kernels showing stains, spots with margins, and black masses of conidiospores and spores. × 2

The seed should be grown in a "wet" nursery, for plants in the dry nursery are more susceptible to the disease. The most promising line of control appears to be in the selection of resistant or less susceptible varieties for planting, especially in areas liable to severe attack.

NARROW BROWN LEAF SPOT. *Cercospora oryzae* Miyake.

This fungus has been recorded in most of the important paddy-growing countries, but has hitherto attracted little attention. The disease may be found on the leaves, sheaths, peduncles, and glumes. It is suggested that by causing the premature killing of leaves and sheaths the disease predisposes the plant to lodging.

The symptoms appear as narrow reddish-brown to dark reddish-brown linear spots. Dickson[69] states that on susceptible varieties the lesion fades to a lighter brown along the margins and is light grey-brown in the older centres, but on more resistant varieties the lesions are smaller and uniform in colour. The lesions are usually more abundant on the leaves, although spots on the sheath, culm, and floral bracts are present in heavy infections. The spots on the floral bracts spread laterally to form oblong lesions.

Varieties of paddy vary considerably in their resistance to the

disease. It is suggested that resistant varieties be grown, and that when infection is very severe and lodging is likely to result, the crop be harvested before fully mature.

STACKBURN DISEASE AND SEEDLING BLIGHT AND LEAF SPOT. *Trichoconis padwickii* Ganguly.

This disease has been reported from the United States as causing damage to grain before and during storage and from India as a disease of the grain in the ear.

It attacks both the roots and coleoptile of seedlings, and occasionally also the leaves, but more generally the grain. Padwick[178] describes the symptoms as dark brown to black spots. As the decay proceeds, discrete, black bodies, more or less spherical in shape, are to be observed lying superficially on the darkened areas. The coleoptile also becomes stained, with brown patches and streaks which become almost black and bearing on their surface scattered, black, minute spherical bodies. Heavily infected seedlings wither and die, but the less severely affected appear to recover from the disease. Grains attacked show, on the glumes, pale brown to almost white, or occasionally faintly pink to reddish-brown discoloured spots of considerable size, usually bounded by a darker ring, and carrying a few to numerous black spots. In severe attack the fungus penetrates the glumes and discolours the kernel.

Little is known regarding the control of the fungus. It is suggested, however, that burning the stubble and old straw should reduce the amount of infective material.

DOWNY MILDEW. *Aclerospora oryzae* Brizi.

This disease does not appear to have assumed great importance. The symptoms seen at time of flowering and formation of the panicle take the form of contorted, sometimes spiral spikes. The leaf-sheath may also be spirally twisted. The panicle is reduced in size and remains green for some time. Occasionally the main rachis is reduced, bearing only a few tufts of hairs in place of rachillae and flowers. On such portions the mycelium may be seen. The stamens and ovaries are completely abortive.

Control of the disease is uncertain. Stubble and straw from an infected crop should be burnt. It is stated that in Japan, growing the transplanted seedlings under dry or semi-dry conditions controls the disease.

LEAF SMUT. *Entyloma oryzae* H. & P. Sydow.

This is an unimportant disease found in many paddy-growing regions. The symptoms are linear, rectangular, or angular-elliptical

spots on the leaves. They are leaden-black in colour, covered by the epidermis. On soaking in water for a few minutes the epidermis ruptures, revealing a black mass of spores beneath.

Bacterial Leaf Blight. *Pseudomonas oryzae* Uyeda & Ishiyama.

This leaf disease has been recorded in the Philippines and Japan, but does not appear to cause serious damage to the crop. It is caused by a bacteria. The symptoms are described as stripes seen between the larger veins of the leaves, running lengthwise, and having a watery dark green, translucent appearance. These spots enlarge lengthwise and may produce a blotch. Amber-coloured droplets of bacteria ooze from the diseased portions. As the leaf dries out, the droplets harden, producing small, roundish, amber-coloured beads.

Control measures are unknown, but as the disease is most prevalent on succulent plants, it is suggested that suitable fertilizers may be effective, while it is possible that resistant varieties may be found.

DISEASES OF THE STEM AND LEAF-SHEATH

Stem Rot. "Sclerotial Disease," "Tiem." *Leptosphaeria salvinii* Catt. = *Sclerotium oryzae* Catt. = *Helminthosporium sigmoideum* Cov.

Stem rot has been recorded in practically every paddy-growing country in the world. By reason of the obscurity of the symptoms and their variations in different countries the disease is often overlooked, or the damage occasioned by it is not fully appreciated. One of the most commonly observed symptoms is excessive late tillering, but while the disease is usually seen on maturing plants in the field, it is also recorded as attacking plants in the nursery. In severely infested areas there is not only loss of grain, but the grain may have inferior milling qualities owing to its light, chalky character.

In some instances, infected plants show no definite symptoms other than light ears and a tendency to tiller when the crop is ripening. Butler,[37] describing the disease in India, states that on splitting the stem a dark greyish weft of hyphae may be found within the hollow stem, and small, round, black, shining bodies (sclerotia) can be seen dotted all over the inner surface. He adds that sometimes the base of the culm is quite free from the fungus and the attack begins at a node some distance up the stem, and that the lower leaf-sheaths are also often attacked. When plants are grown in water, heavy infection is not unusual, and under such conditions the plants may fall to the ground.

Sclerotia will survive in the ground and old stubble for a considerable period, and will also float from field to field in the irrigation water.

The effect of nutrition in relation to the disease was studied by Cralley.[57] He found that excessive nitrogen applications to the soil tended to increase both yields and disease incidence. Excessive phosphorus applications produced the same result, but much less marked. Nitrogen and phosphorus applied together tended to produce higher yields and severer infections than either alone. Potassium applications alone slightly increased the yields and had no effect on disease severity, but when applied with nitrogen and phosphorus in sufficient quantities, potassium maintained the severity of infection as low as the controls or even lower. In fields subject to stem rot, therefore, applications of nitrogen and phosphorus should be well balanced by applications of potassium.

From the foregoing, possible methods of controlling the disease suggest themselves. Where possible, stubble and straw should be burnt, and irrigation water should not flow from an infected area to a non-infected area. In some cases, draining away the water and allowing the soil to bake before again irrigating has been found useful. The inclusion of potash in the manuring programme to offset the adverse effect of applications of nitrogen and phosphates appears to be a most useful line of control. Many varieties of paddy have been found to be resistant to the disease; the cultivation of such varieties is to be recommended.

Irregular Stem Rot, or Sclerotial Disease. *Helminthosporium sigmoideum* Cav. var. *irregulare* Cralley & Tullis.

This disease closely resembles the stem rot described above under the name *Leptosphaeria salvinii* Catt. It has been recorded as occurring in the United States, Japan, the Philippines, and Ceylon. In Ceylon[181] on fully grown infected plants, pale olive-brown patches occur at the first and second internodes from the roots. The diseased culms are hollow and amber-coloured, and small, black sclerotia are seen lining their anterior walls even before the plants are split open. Adventitious roots are produced from the first and second nodes of many of the plants. The culms are found to contain a dark weft of mycelium, and numerous black sclerotia are found embedded in the tissue of the inner surface of the stem. Sclerotia are rarely found on the outer surface of the stems, as distinct from *H. sigmoideum*, which produces them readily externally. The sclerotia are smaller than those of *H. sigmoideum*, less regular in shape, and dull instead of shiny.

In the case of infected seedlings the leaves rapidly wither and turn yellow, and the plants die; with older plants, death, if it occurs, is slower.

It is assumed that control methods are similar to those recommended for controlling stem rot caused by *H. sigmoideum*.

ORIENTAL SHEATH AND LEAF SPOT. *Corticium sasakii* (Sharai) (Matsumoto)

This stem rot has been found in many countries, and may cause considerable damage. It also attacks a large number of other plants, including groundnuts, sweet potatoes, and the water hyacinth. The last-named is very susceptible to the disease and may serve as an important source of infection.

The disease may attack the plant in the seedling stage, in which case considerable losses may occur; if older plants are attacked the loss is less marked, for the outer leaves only are diseased.

The symptom of the disease is discoloration at the base of the culm at water level or higher on the leaf-sheath and leaves. The spots are large and may be at first greenish-grey and ellipsoid, gradually enlarging and becoming greyish-green with a blackish-brown margin.

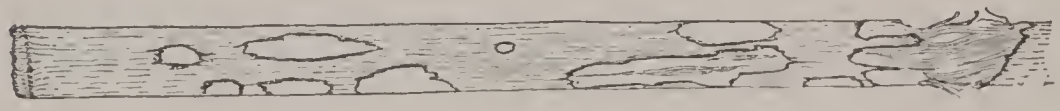


FIG. 19

Oriental sheath spot, *Corticium sasakii*. The sheath has been opened out and spread flat, and the outer surface is depicted. The spots consist of pallid, brittle zones which shed away in the larger spots, surrounded by a thin, dark brown ring which fades away to the straw colour of the non-infected portion. × ½

Oval, spherical, or cushiony sclerotia, brown in colour, frequently covered with brown hyphae, are found on the discoloured areas of leaf and stem, or between the leaf-sheaths.

Little is known about control measures. Burning infected material as far as is possible may assist in controlling the disease. The destruction of alternative host plants in the vicinity is an obvious precaution against the spread of the disease.

RHIZOCTONIA SHEATH SPOT. *Rhizoctonia oryzae* Ryker & Gooch.

This disease, which is of no great importance, is found in the United States, attacks being usually more severe on the bunds and in other places where the paddy growth is dense. It has a great resemblance to Oriental Sheath and Spot Disease, but is usually

restricted to the leaf-sheaths, only occasionally attacking the leaves and never the stems or root.

The spots appear as a reddish-brown discoloration, becoming straw-coloured with reddish-brown margins, and coalescing to form irregular discoloured areas. The spots usually occur just above the water line and often just below the ligule. Control measures have not been studied.

ARKANSAS FOOT ROT OR BROWN SHEATH ROT. *Ophiobolus oryzinus* Sacc.

Arkansas Foot Rot occurs in the United States. The disease infects the leaf-sheath just before harvest, the sheaths so infected showing a brown discoloration from the crown to considerably above the water line. At maturity the straw is dull brown in colour. The disease is at present relatively unimportant. Control measures have not been studied. It is known, however, that certain paddy varieties, including red rice, are susceptible to it.

SEEDLING BLIGHTS AND FOOT ROT

SEEDLING BLIGHT. *Corticium rolfsii* Curzi = *Sclerotium rolfsii* Sacc.

Seedling Blight, which attacks paddy seedlings from a very early stage of growth, is widely distributed throughout most paddy-growing countries.

Tisdale,[256] describing the disease, states that the base of the stems and the roots of diseased plants are dark in colour and often have a frosty appearance due to the presence of wefts of mycelium. Infected plants first show a stunted appearance, accompanied by yellowing and withering of leaves; often, also, the leaves have white stripes or may be almost entirely white. Affected plants die slowly, or the plants may recover when the land is irrigated. The symptoms are readily seen on badly affected seedlings, but plants may be attacked and killed before emergence.

The fungus appears to decrease in prevalence or vigour with a depletion of organic matter in the soil. It can, however, remain in the soil as sclerotia for long periods. The sclerotia float, so that the fungus can be disseminated in irrigation water. The disease is stated to be most common during warm moist weather, and is most severe where there is a lack of water on the seed bed. Irrigation of the seed bed completely checks further development. Control of irrigation on the seed bed appears to offer the best means of controlling the disease.

Seed Rot and Damping Off. Saprolegniaceous and Pythiaceous fungi.

This seedling rot, found in Japan and Formosa, due to one or a number of fungi, may cause severe damage to seedlings. The first evidence of the disease is an outgrowth of the whitish hyphae of the parasites on the surface of the glumes, or on the collar of the plumule. The hyphae may grow from the slit of the seed-coat opened or broken off by the germination or threshing operation, or by insects. When severely attacked, the seed fails to germinate, and if the seedlings are affected when the plumules have already commenced growth, damping off takes place. Progress of the symptoms is influenced by the weather and by the vigour of the seedlings.

Control should aim at the provision of conditions favourable to the development of vigorous seedlings, and the selection of seed free from mechanical injury.

Bakanie Disease and Foot Rot. *Gibberella fujikuroi* (Saw.) Wr.

This disease is well known in Japan under the name "Bakanae," in the Philippines as "Palay Lalake," while the so-called "Man Rice" in British Guiana is probably the same disease. It also occurs in other paddy-growing countries and is frequently responsible for severe damage.

The seedlings attacked in the nursery are pale and thin, and may die out. In the field, the most characteristic symptom (but not always present) is the appearance of occasional lanky tillers which come into shot-blade earlier than the rest of the crop, bearing pale green flags which are conspicuous above the general level of the crop. This "bakanae" symptom, however, may be suppressed and the plants may even be severely stunted. Japanese workers have carried out considerable research on this interesting "bakanae" symptom. Yabuta and Hayasi[274] isolated two substances from cultures of *G. fujikuroi*; one they named fusaric acid has a formula $C_{10}N_{13}NO_2$ retards the growth of seedlings; the other, named gibberellin, which they thought to be an organic acid, stimulated the elongation of shoots of a variety of plants, including paddy. Several writers have noted that in fields where the temperature during the growing period is low, practically no "bakanae" plants can be found.

Thomas,[251] in describing the symptoms of the disease, observes that plants with the "bakanae" symptom invariably show fungus attack at the collar region and die within a period of two to six days. He adds that as a rule the leaves of infected plants dry up one after another from below, their margins first turning brown, while a long strip along both sides of the mid-rib still remains green. Eventually

the green area also turns brown, when the leaf curls and droops. Another symptom described by the same writer is the development of adventitious roots from the first, second, and sometimes the third node above ground level. The first node exhibits well-developed roots, while the node above it may show a few developed roots or early signs of such development. The account continues:

> On splitting open the culm of the infected tiller, there is a distinct crown discoloration of the spongy tissue of the nodular region confined in early cases of attack to the lowest root-bearing nodes but visible in advanced stages at the upper one or two nodes as well. In the latter case, long before the death of the tiller the fungus growth is found to spread through the hollow of the lowest internode. Though the root-bearing nodes are discoloured within, the underground root system remains intact, showing the healthy white colour.
>
> Some plants which develop the symptoms described above show externally a white or pink bloom of fungus growth at the lowest one or two nodes. This bloom is often conspicuous on the dead sheaths. When the plants are dead, the bloom extends upwards along the sheath up to a distance of four inches above the collar. If the dead plants are left in the field sufficiently long, the fungous growth on the sheath develops into a pink incrustation which consists of a thick matting of mycelium bearing myriads of conidia (spores). When irrigation water stands at a high level, the portion of the sheath under water does not show the white bloom, but when the field gets drained, the bloom is evident down to ground level. Dead plants when pulled out snap at the collar, leaving the root behind.

An additional symptom that may be found is a fasciculation of the root due to the abnormal branching of the main roots.

The disease may be carried in the seed, or be soil-borne, soil moisture and soil temperature playing an important part in its development. Nitrogen applied to the soil stimulates the disease, an effect that is not modified by the addition of potash or phosphates.

Certain varieties of paddy are more resistant to the disease than are others. It is probable that further research regarding resistant varieties may lead to favourable results. The treatment of seed with formalin and with mercurial dusts is effective.

DISEASES OF THE GRAIN AND INFLORESCENCE

BLACK SMUT OR BUNT. *Neovossia horrida* (Tak.) Padwick & Azmatullah Khan.

Black Smut has been recorded from many countries, but is not considered to be a serious disease, as usually only a few ears are attacked, and these often only partially. In this disease the grain is

wholly or partly filled with black spores, which burst through the glumes at the time of ripening.

The disease is said to be more prevalent when paddy is irrigated during dry weather than when planted during the normal growing season.

It is doubtful whether seed treatment with one of the recognized disinfectants is effective in controlling the disease. Certain varieties of paddy are said to be resistant to the disease.

False Smut or Green Smut. *Ustilaginoidea virens* (Cke.) Tak.

Although this disease is widely distributed it rarely causes much damage. The infected grains are transformed into large, velvety, green masses which may be twice the diameter of the normal grain. The green colour is superficial, the inner part of the swollen mass being orange-yellow near the surface and white in the centre.

Satisfactory control measures are not known. When paddy is milled by hand, the diseased grains are easily recognized and can be removed by hand.

Minute Leaf and Grain Spot. *Nigrospora* spp.

This condition of the ears and grains of rice occurs usually on plants already weakened by other causes, such as malnutrition, insect pests, and diseases, and the symptoms are usually those caused by the primary agent. The fungi associated with this condition of rice are three species of the genus Nigrospora (Moniliales). The disease appears to be of minor importance, and there is no information on methods of control.

"Udbatta" Disease. *Ephelis oryzae* Syd.

"Udbatta" disease attacks paddy in India, and has also been reported to attack certain other grasses. The symptom is characteristic: the ear, on emergence, is reduced to a straight spike and covered with mycelium, which becomes hard and dotted with black. No grain is formed.

Scab. *Gibberella zeae* (Schw.) Petch.

Scab has been reported from many rice-producing regions, and is identical with scab disease of wheat. Infected grains may show a reddish appearance and discoloration appears as brown spots covering the entire seed. The infected grain is light, shrunken, and brittle, but the seeds do not necessarily show signs of infection. Diseased grain gives rise to diseased seedlings. The nodes may also be attacked; they become blackened and disintegrate, the stems wilt, break down, and fall.

Treatment of seed with mercurial dressing may offer some degree of control.

BLACK ROT OF RICE GRAINS. *Pseudomonas itoana* Tochinai.

Iwadara[120] states that the disease is characterized by partial blackening or black spotting on the hulled grain, especially at the apical part, sometimes at the middle, and rarely at the base. The centre of the black spot usually lies on the apex or on the groove of the grain. It is stated that the morbid change is limited mostly to the aleurone layer and the upper parts of the endosperm. The affected tissues die off and turn black.

The causal organism attacks the rice grain at its milky-white stage through wounds. The disease occurs most severely in years when the temperature is high in July and August. Control measures have not been stated.

DISEASES CAUSED BY NEMATODES

"UFRA" OR "DAK PORA." *Ditylenchus angustus* (Butler) Filipjev.

"Ufra" is a serious disease in the restricted area of eastern Bengal and has also been reported from Malaya and Burma. The disease was the subject of close study by Butler.[38, 40] The attack may commence at an early stage in the development of the plant, and given favourable conditions from the time of infection until maturity the plants produce little or no grain. The most severe attacks affect the floating varieties of paddy broadcasted in the low swamp areas which remain submerged for most of the year and are either damp or actually under water at harvest time.

Although seedlings may be attacked by the disease at an early stage, the death of seedlings due to ufra is probably rare. The disease is first evident when the plants are about two months old, but it may not be apparent until the ears begin to form in the bud. The upper leaves are chlorotic as a whole or in streaks, and are thin and weak, and the plant is somewhat stunted. The plants have, in fact, been infected for a considerable time before these symptoms are seen. Later, a few scattered brown stains appear on the leaves and sheaths. The inner layers of the sheaths may be faintly stained brown, and there is a tendency towards wrinkling of the layers. Later the stains become darker and the stems in portions of the upper internodes become quite dark brown. There are two distinct types of symptoms seen at heading-out time, viz. "thor" or swollen ufra, and "pucca" or ripe ufra. In the former, the ear remains entirely enclosed within the leaf-sheath, the whole structure being enlarged into a spindle-shaped swelling. The sheath may be stained

over a considerable area or confined to small oval or elliptical spots. The spiral twisting of the ear, coupled with the dark-brown colour, and the absence in most cases of insect attack, are characteristic of the disease. There may also be a tendency towards branching of the stem in the infected portions, and even the formation of two or three distorted ears surrounded by one sheath. In "pucca" ufra the ear emerges from the sheath and usually produces some normal grains, especially near the tip. The peduncle turns brown or black, and the flowers in the lower part of the ear remain unfertilized and have the typical brown colour, or may contain partly formed grains.

FIG. 20

Ufra disease, *Ditylenchus angustus*.
A severe attack showing the spirally twisted inflorescence. × ½

A microscopic examination of affected material at harvest reveals the presence of nematodes. They are mainly found at the base of the peduncle, the stem just above the next node lower down, and in the glumes. These are the areas which have the typical discoloration.

Infection takes place, if humidity is sufficient, even when seedlings are four days old. They climb up the stems and attack the growing tissues. They enter the bud and can find their way into the inner portions by working their way between the folds. They do not penetrate bodily through the tissues, but protrude their stylets, which are inserted into the epidermal cells and suck the sap of the plants. The nematode is believed to be incapable of feeding on decomposing vegetable matter, or on any plant other than paddy.

Unless land can be drained or adequately cultivated, the only effective method of controlling the disease is by the complete removal of all infected straw. It is stated that so long as affected fields are

used for cattle-grazing without removal of the straw, or so long as a crop such as gram is broadcast amongst the ripening and partly diseased crop, there is no hope of destroying the dormant nematodes by physical means.

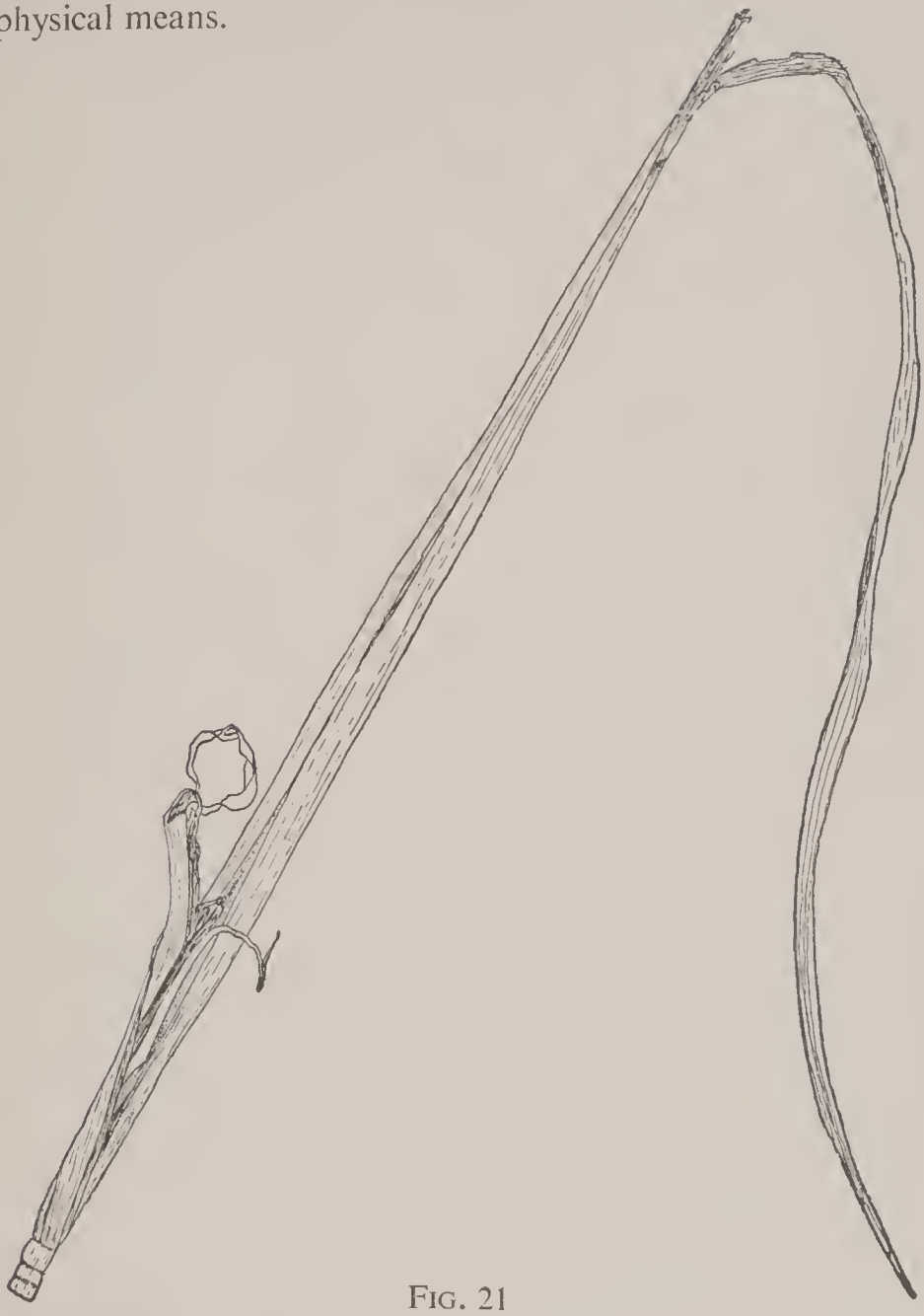


FIG. 21

Ufra disease, *Ditylenchus angustus*. A very severe attack ('thor ufra'), the inflorescence being almost unrecognizable. × ½

DISEASES CAUSED BY UNFAVOURABLE SOIL CONDITIONS

STRAIGHTHEAD

Straighthead is a symptom of a physiological condition that may be due to one of several causes. Under various names it occurs in

many countries, and in the United States, where it is common, it sometimes causes extensive damage.

The leaves of diseased plants turn a deeper green and are stiffer than usual. The heads emerge slowly, or the plants may even fail to head. The entire flower may be absent, or only one glume is absent and the other distorted and curved. Sterile flowers may be present and most of the flowers never open, while others open but fail to produce kernels. The plant produces numerous tillers from the lower nodes and crown. These develop into secondary growth after harvest. The root system is enlarged by long coarse roots, showing only a few ramifications and root-hairs.

FIG. 22
Inflorescence of a rice plant suffering from 'straighthead.' × ½

Straighthead occurs only after the most unfavourable conditions of soil aeration when certain other conditions are satisfied. It is most severe when paddy follows a series of non-irrigated crops, or on virgin land. The nature of a superabundance of organic matter is thought to be a contributory cause.

Control measures recommended in the United States by Tisdale and Jenkins[257] include thorough preparation of the land before sowing, followed by irrigation to a depth of about four inches about ten days after the plants emerge, or when they are about six to eight inches tall. Where attack is anticipated, the soil should be drained five to six weeks after the application of water; it should be allowed to dry until the surface cracks, the water then being again applied to a depth of four to five inches and retained thus for the remainder of the growing period.

Straighthead symptoms may be due to climatic causes. Dickson[69] instances the disease occurring in Italy known as "bianchetta" or "gentilomo" with similar symptoms, except that the stalk bearing the panicle is said to rot. The cause is thought to be a sudden decrease in temperature in the later stages of growth, or to hail storms. In the disease in Italy called "colatura," where the panicle stands upright, part of the inflorescence fails, and the organs of the blossoms are turned into a "tuft of white threads," the probable causes are thought to be decrease in temperature, hail storms at the time of formation of the panicle, lack of nutrients, or to high nitrogen content.

Dry Leaf Disease or Pan-Sukh occurring in India has symptoms very similar to those of Straighthead. Only a few green leaves are seen amongst a mass of brown dry leaves. The flowers are sterile but the glumes are normal in shape and colour and there is no distortion. The root symptoms are identical with those of Straighthead. The disease appears to be mainly due to poor soil aeration, accentuated by, or possibly resulting in, lack of available nitrogen. Resistant varieties of paddy are known.

FIG. 23

Straighthead. On the left a grain from a healthy plant, the remainder from a diseased plant. Note the sickle shape, the absence of one glume, and the hollow shrunken appearance. × 2

STERILITY

Sterility in paddy may be caused by certain of the diseases mentioned or by other causes. Tisdale and Jenkins[257] suggest the following additional types of sterility:

Alkali injury resulting in stunted and rusty appearance of the plants, and failure to produce seed. Drought injury resulting in death. Nitre spots, the symptoms being retention of green colour up to harvest time, the plants remaining sterile and erect though otherwise lacking the straighthead symptoms. Dry hot winds give a blasted appearance of the heads as if scorched by fire. Poor grassy land results in sterility, commonly accompanied by staining of the glumes due to invading fungi.

Other diseases caused by unfavourable soil conditions include a disease reported from Japan[172] caused by lack of oxygen in the soil, brought about by the sulphate-reducing bacteria, *Microspira desulphuricans* (Beijerinck) van Delden and *Pseudomonas* sp. The symptoms are curving and checking of elongation of the first leaf, which eventually dies and rots, and checking of development of the root, which withers and is blackened. In the disease known as "Senthal" in Ceylon[180] the central shoot becomes pinkish and tubular, and fails to develop further, but tillering is stimulated under favourable conditions. It occurs chiefly on sandy soils which have had a heavy application of bulky green manures which have not decayed completely.

DEFICIENCY DISEASES*

Nitrogen. A nitrogen-deficiency disease, known as *Cadang-cadang*, is described from the Philippines. The affected plants manifest a yellowing of the leaves, the older becoming light orange or

* See also Trace Elements on page 178.

yellow. The roots are almost brown. Applications of nitrogenous fertilizers appear effective in controlling the disease.

Phosphorus. In central Burma phosphate deficiency caused the crop to remain green at the normal time of maturity. The symptoms of phosphorus deficiency were found to include stunting, reduced tillering, bunching of leaves, and a dark or blue tinge.

Potash. The disease known as "Mentek" in Java has probably been applied to a number of diseases with somewhat similar symptoms. From time to time, considerable damage is caused by this disease in Java and Sumatra. The term "Mentek" there refers to a combination of shortening of the leaf-blades and sheaths from an early stage, accompanied by yellowing and partial failure of emergence of the ears and reduction in length of the culms. Nitrogen potash and phosphate deficiency are considered possible causes of the disease.

Iron. Chlorosis of paddy occurring on calcareous soils is considered to be due to the iron being rendered unavailable.

Calcium and Magnesium. The "White Tip" disease in the United States appears as white areas on the tips of one or more of the new leaves during the mid-season or late flowering period. If the flag-leaf is affected the panicle remains tightly enrolled within its sheath, the head often emerging through the side, giving rise to only a few sterile flowers, or at best, distorted grains. While there appears to be some evidence that the trouble may be caused by calcium and magnesium deficiency, there is also contradictory evidence.

Boron, Copper, and Manganese. Boron deficiency is stated[106] to result in chlorotic spotting of leaves at the tip; manganese deficiency to chlorosis of the mid-vein, with a resultant striped appearance of the foliage; and copper deficiency in reduced weight of plants.

Sulphur. A disease said to be due to sulphur deficiency is reported from Burma. The plants turn yellow and remain stunted; later they regain their green colour and increase in height, but give a reduced yield. It is found that the plants regain their green colour when fertilized with chemicals containing sulphate.

VIRUS DISEASES

Dwarf or Stunt Disease

Until the cause of this disease was discovered, resulting in steps being taken to control its cause, widespread damage was experienced in Japan.

The disease manifests itself as yellowish-white specks along the veins of newly unfolded leaves. These specks elongate and spread

out along the leaf parallel to the mid-rib, forming fine interrupted streaks. Growth is stunted, the internodes shortened, and numerous diminutive tillers develop, producing a rosette appearance. Affected plants tend to develop foliage dark green in colour. The roots are much arrested in growth and only small roots develop extending horizontally.

The infectiousness of the disease, the invisibility of the causal agent under the microscope, and the mode of transmission, all point to the fact that it is caused by a virus. Though much is known about its transmission there is little information about its physical and chemical properties. It was early discovered by the Japanese that the disease is transmitted by certain leafhoppers, viz. *Nephotettix apicalis* Motsch var. *cincticeps* Uhl. and by *Deltocephalus dorsalis* Motsch. There is no known method of control of the disease other than by control of the vector.

Stripe Disease

This disease, unknown outside Japan, first appears about ten days after transplanting and becomes more destructive as the plants grow. The young leaves show the symptoms, twisting, abnormal elongation, and final drooping. The leaves of the affected plants appear slender and pale and one or more yellowish-green or yellowish-white stripes develop parallel to the mid-rib. The plants usually produce no ears, or at best, unfilled ears. The disease is caused by a virus transmitted by *Delphacodes striatella* Fall. No control measures are known.

Chapter VIII

METHODS OF CULTIVATION

Traditional Methods—Wet and Dry Systems—Sowing the Seed in the Field—The Dry Nursery—The Wet Nursery—Multiple Nurseries—Fertilizing the Seedlings—Broadcasting versus Transplanting—Preparation of Land—Transplanting—After-cultivation—Harvesting—Threshing—Winnowing—Double-cropping Systems—Fortuitous Paddy Crops—Rotations—Red Rice—Weeds.

TRADITIONAL METHODS

As a result of centuries of experience, the systems of cultivation, although simple, have reached a high degree of efficiency in many Asian countries, but the implements used continue to be most primitive, in many cases improvised to suit local conditions. Throughout the great rice-producing areas of Asia it is the rule rather than the exception for the crop to be cultivated with primitive implements, and despite efforts in many directions to introduce more modern methods, the old order survives. The reluctance of the cultivator to accept innovations may, to some extent, be due to conservatism, but there are additional reasons for his apparent apathy. He is a peasant, cultivating usually from one to five acres, and without co-operation or other financial assistance he lacks the capital to enable him to purchase new and to him expensive implements, and although his customary methods are expensive in labour, this is of little moment, for he and his family perform the necessary tasks. It is, therefore, the traditional methods of cultivation that are still of first importance, methods that have changed but little in the past thousand years, that must be largely considered in this place.

WET AND DRY SYSTEMS

There are two main systems of paddy cultivation; the dry system, in which the crop is grown on dry ground, very much in the same way as are other cereals; and the wet system, in which the land is inundated and the crop grown in water from the time of transplanting until harvest approaches. "Dry" paddy cultivation is relatively

unimportant at the present time, for "wet" paddy supplies practically the entire world market. This latter system, therefore, is the subject under consideration in this chapter.

SOWING THE SEED IN THE FIELD

The seed may either be broadcast or drilled direct in the field or it may be cultivated in nurseries and subsequently transplanted when the seedlings have reached a suitable stage of development.

The sowing of the seed in the field has for long been commonly practised in India and Ceylon, and is usual in the large-scale mechanized methods of cultivation.

In Ceylon, two methods of sowing the field are recognized, viz. dry-land sowing and wet-land sowing. The first-named method is stated to be necessary where the rainfall or irrigation facilities are inadequate for puddling the soil. The seed is usually broadcast or drilled without previous germination, though if the rains can be depended upon to fall soon after sowing, the seed may be germinated before sowing. The seed is covered by the plough or the local hoe—the *mamoty*. The seed remains dormant in the soil until the advent of rain. Subsequently, the land is flooded as the plants grow, the water being drawn off when the ears are past the "milk" stage. Where there is a sufficient supply of water for the fields to be puddled, sprouted seed is sown as soon as the final levelling of the soft mud has been effected. In this case the seed is invariably broadcast as there are practical difficulties in drilling sprouted seed in soft mud. The seed sinks into the mud and soon develops, the depth of water on the field being regulated in the usual manner as the plants grow.

Jack[122] states that in Malaya direct broadcasting in the field is resorted to only where the water can be run off the field a few days after sowing unsoaked seed, and run on again after the young plants are several inches high.

The cultural methods of sowing in Japan depend on the climate of the region. Leonard[139] states that in the cold regions (Hokkaido) it is usual to sow the seed in the field, in the cool climate of Tokaku transplanting is practised with early sowing and early planting of early varieties; in the medium climate of mid-Honshu the ordinary transplanting system is followed; while in the warm climate of south Honshu, Shikoku, and Kyushu, transplanting is carried out with somewhat late sowing and with late varieties.

Broadcasting is the usual method in the Central Provinces of India, although in recent years the practice of transplanting has been introduced and its popularity has increased. Broadcasting is done just before or after the rains have started, sometimes with germinated

seed. Another system mentioned by Graham[87A] is the broadcasting of seed followed by a second ploughing when the plants are about a foot high. The method has been more fully described by Clouston[148] who states that the system known as *Biasi* consists of ploughing once before sowing the seed. The seed is broadcasted at the rate of 100 lb. per acre. When the plants are one foot high, the land is ploughed, which uproots many of the plants and covers some with mud. The plants are thus thinned out and the root system of those that remain is strengthened. Five to six days later the field is levelled, which flattens all the surviving plants. In five or six days weeding operations commence, followed by further weeding on two occasions at intervals of about a fortnight.

THE DRY NURSERY

The alternative to broadcasting or drilling the seed in the field is to raise seedlings in a nursery to be transplanted in the field when they have attained sufficient development. The nursery may be situated on dry land or in a "wet" situation, the latter being the more usual. The main difference between a dry and wet nursery is that the paddy seedlings may remain in the former for as long as three months before transplanting, whereas the seedlings from a wet nursery must be transplanted after about forty days or they become too developed for the purpose. In cases where the water supply is precarious it is therefore an advantage to be able to postpone transplanting till field conditions are suitable. The writer has found no evidence that the crop is in any way inferior when seedlings from a dry nursery are employed, provided that the dry nursery is efficiently cultivated and, if necessary, manured.

The dry nursery should be well cultivated and manured, and adequately protected from fowls, ducks, and birds. The seed is steeped in water for a few hours and immediately broadcasted thickly on the nursery bed and covered with an inch or so of fine soil. The seedlings from such a nursery may be transplanted at any time after forty days' growth.

The use of the dry nursery is common in parts of Malaya. In British Guiana[203] the seed is planted either by broadcasting (locally known as "shying") or by transplanting at six weeks plants raised in either a wet or dry nursery. On the saline soils of Sind, India,[153] the seedlings are raised in a dry nursery.

THE WET NURSERY

In the wet nursery the seed is planted in soft mud and the nursery inundated after the seed has germinated. The land is usually fenced

in and ploughed or dug. All weeds are removed, lumps of clay broken down, so that the land is brought to a condition of fine mud. In Burma, the soil is worked into a condition of soft mud to a depth of five or six inches. The water is then drained off. Meanwhile seed has been steeped in water for a night and kept in a cool place for a further two days, by which time it will have germinated. The germinated seed is broadcasted thickly over the nursery, but no soil is placed over it. Should there be any standing water on any part of the nursery it is unlikely that the seed will survive in it. In a week's time the seedlings are perhaps two or three inches high and the growth very dense. In this condition seedlings are capable of surviving a deep flood for three or four days, but are easily swept away by water in motion. As the seedlings develop, water is sometimes let out of the nursery until the time of transplanting at forty days, when the nursery may be moderately dry.

In most countries manuring of the nursery is considered to be of secondary importance, and over-manuring of the nursery held to be a mistake, as it is said to cause the plants to become too developed and the stems too weak. In Japan, however, as well as in China, infinite care is exercised in the preparation of the nursery. Leonard[139] gives a precise account of the system obtaining in Japan. He states that the preparation of the seed for planting consists of sifting to remove small or withered seed and then placing the good seed in a salt solution of specific gravity 1·13 to separate the heavy from the light seed. This practice is common in many rice-producing areas in Asia; sometimes instead of salt a "thin" mixture of clay and water is used for the purpose. In Japan, to control seed-borne diseases, after the seed has been soaked in water for one or two days it is then soaked in 40 per cent formalin diluted fifty times with water.

In many districts in Java the nurseries are manured with organic matter, such as stable dung, waste products, or compost, and for this purpose fallen leaves and green material of various plants are gathered.[83]

In the cool areas of Tohaku the seedlings are raised in hotbeds in order to produce satisfactory plant growth despite the low temperature. Mixed or organic manures are dug into the seed bed and sulphate of ammonia and other water-soluble fertilizers are mixed with the soil before sowing, and wood ash applied when the seedlings are about one inch in height. More nitrogen is applied in cold than in warm areas. The seedlings are thinned in the seed bed several times, weeds being removed at the same time. The beds are drained of water in the mornings to raise the temperature and irrigated in the late afternoon to maintain the temperature fairly uniformly

during the night. In Korea,[76] because of severe winters and the short growing season the nurseries are planted as early as possible. Frequent frosts are therefore likely after the seed germinates. To protect the growing plants from the frost, the nursery is flooded every night so that the plants are completely inundated, the water being drained off in the mornings.

In China, great care is taken in the preparation of the nursery. In Hong Kong,[105] the nursery is twice manured after thorough cultivation. The first manuring is made four days before transplanting, and for a nursery of 500 sq. ft. about 10 lb. bone meal, 5 lb. fish meal, and 130 lb. of a mixture of 80 per cent finely ground cow dung and 20 per cent ashes from grass and brushwood are applied. The second dressing is given the night before transplanting and may consist of about 10 lb. powdered peanut cake or fish meal. For the first crop paddy germination commences the third day after soaking, and the seed is ready for sowing when the first roots are about $\frac{1}{4}$ inch long. For the second crop, germination takes place the day following soaking and the grain is ready for sowing.

In western India, a specialized method of seed-bed preparation is practised, known as *Rab*. Copeland,[51] quoting from an Indian publication,[150] describes it as follows. The method consists in burning the seed bed and is practised from Nerbudda in the north to Kanara in the south wherever quality of the rice is a prime consideration. This area is characterized as a whole as one of very heavy, sticky soil, exceedingly hard when dry and tenacious when wet. It is claimed that except by this practice rice fit to transplant cannot be produced. The seed bed is covered with a layer of cow dung superimposed with a layer of branches and other combustible matter, the whole being covered with a layer of soil. The burning is done shortly before the rains are expected, after which the bed is thoroughly cultivated and planted. When the field has been transplanted with seedlings from this nursery, the seed bed itself is transplanted and is said to produce the finest crop, which is saved for seed.

Copeland also describes a seed-bed method used in the Philippines whenever early maturity is required.

> The seed bed is placed where water is at hand, and puddled and smoothed in the usual way. Banana leaves are then split down the middle to the mid-rib, the narrowed ends cut off and placed edge to edge, and pressed in so that a very little mud oozes over them. Holes and torn places in the leaves, and places where they do not quite meet, are covered with pieces of leaf. To be sure that there can be no open holes left, the beds may be made more than one leaf thick. The beds thus formed are a yard or a metre wide, and indefinitely long. At the

ends they are closed by leaves laid crosswise with the edge inwards, so that each whole bed is surrounded by a raised border, made by the midribs. As a matter of convenience, two or more such beds may be made side by side. A cavan* of seed will plant two such beds about fifty feet long, which is accordingly the usual length. The beds are then covered with a layer of rice hulls or finely cut straw about an inch thick, which is wet with muddy water.

The seed is soaked and germinated in the usual manner, and scattered thickly over the bed. Constant care is required to keep it wet, at first by sprinkling, and then, as the roots grow and begin to make a mat, by flowing water. If the weather is hot and clear, the beds need to be shaded, which is done with banana leaves or bamboo branches placed on frames. Transplanting is performed within two weeks after germination. Only early varieties are handled in this way.

MULTIPLE NURSERIES

The nursery method of raising seedlings in the Krian District of the State of Perak in Malaya has been described by Jack.[122] The method appears to be peculiar to this district, an area that is noteworthy for high yields. Grass is cut and piled in a long strip, about three or four feet wide and standing about an inch above water level. Mud is plastered on this to make a compact, solid bed, and more mud, rich in humus, is superimposed. The seed is broadcasted thickly over the bed in the cool of the evening. The allowance is about 18 lb. seed for the eventual planting out of one acre. The nursery is watered twice daily, and when the seedlings are about four to five inches high the nursery is lowered to the level of the surface of the surrounding water by pulling out grass from underneath. This ensures thorough wetness and also protection against the mole cricket, *Gryllotalpa borealis*, which otherwise would attack the rootlets. When the seedlings are ten to twelve inches high, usually after twelve to sixteen days in the nursery, they are pulled up in clumps of 150 to 200; these clumps are placed, still as clumps, in a second nursery of ploughed land where they remain for about six days in about two inches of water. Each clump is then subdivided into about six smaller clumps which are placed in a prepared bed of mud. Twenty days later, by which time the plants are about $2\frac{1}{2}$ feet high, the clumps are again divided into bunches of from ten to twelve plants, the clumps being planted in rows and spaced two feet apart. Final transplanting into the field takes place about forty days later.

Commenting on this system of multiple transplanting, Jack[122] makes the following observations:

* The cavan is the usual "sack" (about 100 lb. seed).

The physiological factors involved in transplanting are somewhat obscure, but the conclusion at present, based on a number of experiments, is that transplantation acts in a similar way to root pruning, the injury to the root system stimulating growth of the sub-aerial portion and resulting in increased tillering. The root system of transplanted rice is developed from the lower nodes of the stem, the first or seedling root system dying completely in most cases. In very rich soil like that in Krian complete amputation of the original root system is the usual practice. It was found that, in the best soils of Krian where three transplantations are the rule, seedlings that had only been transplanted once gave a large vegetative growth but practically no grain. It was also found that if the original root system was not heavily pruned at the final transplantation the resulting plants were slow growing and eventually gave little grain.

In British Guiana[49] double transplanting was found to result in a higher yield, stronger seedlings, more efficient weed control, and economy in seed. The additional expenditure was more than counterbalanced by the increase in yield. Double transplanting, however, is not commonly practised in British Guiana.

FERTILIZING THE SEEDLINGS

In some cases, the roots of seedlings are steeped in a semi-liquid mixture containing fertilizer of some sort, usually guano or cattle manure, before being planted in the field. In some parts of Kyushu, Japan,[208] where soils are derived from volcanic ash and fix phosphates very strongly, a thin mud paste is made by mixing one part of superphosphate with about five parts of soil. The roots of the seedlings are dipped into this "mud" just before transplanting. The practice of concentrating phosphates around the roots tends partially to reduce the loss of phosphates through phosphate fixation.

The quantity of seed required to transplant an acre varies, rich land requiring less seedlings per "hill" and wider spacing than when planting poorer land. The amount required also depends on the variety of paddy. The usual rate is about 20 lb. per acre for good land, up to about 40 lb. for poorer land, or for short-maturation varieties.

BROADCASTING *versus* TRANSPLANTING

It is the experience in all the more important areas of production in the East, and proved by innumerable experiments, that higher yields may be expected from transplanted paddy than from direct broadcasting or drilling in the field. Lord[145] states that experiments in Ceylon have shown that with six or seven months' paddy, trans-

21. Multiple transplanting of paddy. The first transplanting of seedlings, Malaya

22. Sowing germinated seed on a floating nursery, Malaya

23. Tilling the paddy field with a wooden plough, Malaya

24. A wooden harrow, Malaya

25. A wooden ribbed roller used for making the mud soft and reducing all lumps, Malaya

26. Smoothing the mud—the final operation before transplanting, Bihar

27. Removing seedlings from nursery, Bihar

28. Planting out paddy seedlings in the flooded fields, India

29. Cutting roots and tops preparatory to transplanting, Malaya

30. Removing seedlings from nursery, Hong Kong

31. Assamese peasant family reaping paddy

32. Harvested paddy fields, Bihar

3. Harvesting paddy with the tuai, a knife that cuts ear by ear, Malaya

34. Harvesting with the sickle, Malaya

35. Threshing paddy in the field, Malaya

36. Threshing paddy with a bullock team, Bihar

37. Threshing paddy by treading, Malabar

planting increases the crop by 30 to 46 per cent; with the three to four months' varieties, which occupy most of the paddy area in Ceylon, it is doubtful whether transplanting will prove profitable. Paul[184] considers that transplanting in Ceylon is superior to broadcasting, but not necessarily to drilling. Field trials in Ceylon[272] have also confirmed the conclusion that yields of paddy sown broadcast can be considerably increased by harrowing the crop when the seedlings are three to four weeks old. When the standard of cultivation is poor the response to harrowing is said to be greater.

Experiments in the Philippines[179] proved that transplanted paddy develops faster, is more uniform and is taller, and matures later than broadcasted seed. The mean yields were 2,880 lb. and 1,920 lb. per acre for transplanted and broadcasted seed respectively. Clouston[48] states that a transplanted field can easily be detected as the transplanted plants tiller more than if sown broadcast, and the ground is more free of weeds.

In Italy, paddy is either drilled or broadcast, or more usually transplanted by mechanical means. It is held[250] that transplanting induces a higher yield, gives a more regular stand, facilitates weeding, and reduces the amount of supplying necessary, and also shortens the period during which the crop occupies the land.

In many quarters, however, doubt is expressed as to whether the transplanting of paddy results in higher yields, or whether it is only justified as enabling the land to carry more than one crop per annum and to assist in maintaining the land reasonably free of weeds. Wickizer and Bennett[271] point out that "in some parts of Japan rice has been sown directly on the paddy-field as thickly as is customary with transplanted rice, and the yields have been approximately the same. Furthermore, although there is no transplanting in California, yields there compare favourably with those obtaining in parts of the Orient (other than Japan) where yields are fairly high." Adair[1] in the United States, too, has stated that as a result of trials over a period of three years no significant differences in average yield resulted from the two procedures of transplanted or direct-sown rice.

Wickizer and Bennett should not, however, compare the yields of broadcasted seed in the United States with yields in tropical Asia, but with yields in countries with similar climatic conditions to those of the paddy-growing areas of the United States.

One can but emphasize the fact that the weight of evidence throughout the paddy areas of the world is that transplanting is beneficial to the plant and results directly in increased yields. While other factors must be taken into account to explain the high yields obtained in

certain countries, notably Japan, China, and Spain, in all these countries transplanting is the accepted custom and not the exception, and very great care is taken in the preparation of the nursery.

It must be admitted that transplanting offers difficulties, the chief of which is the necessity of hand labour, but where these difficulties can be overcome, or circumvented by the use of mechanical transplanters, transplanting should be the invariable practice in the cultivation of paddy.

It has been rightly pointed out that one of the main virtues of transplanting (but not the most important) is the ability it offers to control weeds in the field. This weed problem is proving a limiting factor in rice production in the United States and may perhaps only be solved when economic conditions make it possible to introduce transplanting in this region. Wickizer and Bennett[271] would appear to retain an open mind on this subject, for they state: "On lands where at present only one rice crop and no other crop is grown each year, some of the chief potential advantages of transplanting cannot be realized. Future changes that may involve an extension of the practice are unpredictable. Some potentialities for bettering rice yields by this method undoubtedly exist, but their magnitude remains unknown."

PREPARATION OF LAND

Local custom, the nature of the soil, and the water supply are amongst the principal factors responsible for the various methods employed for preparing the land to receive the paddy seedlings. Where the water is under good control, the earlier operations may be similar to those usual in the cultivation of a dry-land crop, but where the land is really a swamp, as is often the case, other methods are rendered necessary and have become customary.

By far the greater area planted with paddy is on land subject to seasonal flooding, and the cultivator's aim, therefore, is to take the fullest advantage of the rains. In Burma,[201] for instance, there are three sets of conditions under which the crop is raised: low-lying swamp land where rainfall is sufficient throughout the growing period to keep the plant in its necessary state of submergence; land less low-lying, or with less rainfall, but having supplementary water available from natural drainage and seepage, or from irrigation schemes; and land bordering tanks or rivers and subject to flood on which successive plantings can be made, level by level, as the flood water subsides.

Somewhat similar variations are found in most paddy-growing countries. By growing the appropriate variety of seed, and by adopt-

ing the system of cultivation to meet local variations of soil and water supply, widely varying types of land are cultivated, in conditions where water supply is uncertain and at best not plentiful to the planting of deep and undrained swamp. It frequently happens, too, that widely varying conditions are encountered within a comparatively small area.

The first operation in the field is usually that of repairing and cleaning waterways and making and repairing the bunds. A paddy-field is divided into divisions separated by bunds, the size and shape of the divisions depending on the contour of the land. In fairly flat and open country a division may embrace an acre or more, the bunds being in straight lines, whereas where hillside land is utilized and irrigated from a stream, the divisions will be small and irregular, the bunds conforming to the contour. Contour bunding should always be adopted, in open country only after a careful contour survey of the area. The bunds are constructed of compacted clay, stiff mud, and weeds, openings being made at convenient places for ingress and egress of water. Land within a division is approximately level, so that should it be necessary to conserve water within a division, the exit is closed with mud, and the water contained in the division will be at one level.

It is obvious that where the divisions bunded are small, ploughing is difficult and in some cases impossible, and recourse is then made to cultivation with hand implements. However, many of the animal-driven implements are light, being made of wood, and so may be employed in the cultivation of fields that are much divided by bunds, the operator lifting the implement over the bunds. One division is usually cultivated at a time to limit the amount of lifting of implements. It is usually not possible to plough the land before bunding, as the bunds are necessary to impound the water and thereby to render the soil soft enough to take the primitive plough.

The land is now turned over with a plough or one of the various forms of hand implements, and in this way the weeds are turned under the mud. This work is preferably done with three or four inches of water on the land.

The choice of implement used in cultivation varies according to the nature of the land. Heavy weed growth may be cut down before ploughing. The plough is single-furrowed, composed of wood with the exception of the coulter, which is usually of iron. Light iron ploughs are frequently seen in place of the wooden plough. Ploughs are drawn by one or two buffalo or by oxen, and usually till the ground for not more than two to three inches. Deep ploughing for paddy is usually unnecessary.

Where the nature of the land does not permit the use of the plough, the *chankol* may be used. This is an implement known and widely used throughout the East. It is a draw hoe with a blade of varying weight and shape according to the nature of the work, but it is usually about fifteen inches long and twelve inches wide. It is set at an acute angle to the handle. A somewhat similar implement but with prongs instead of a blade is also used to break up very heavy land. Nowhere in the East does one find a spade used by a native, probably because they work with bare feet.

A wooden ribbed roller is used for making the mud soft and for reducing all lumps. It is drawn over the land just before transplanting, yoked to a buffalo or drawn by hand.

An hexagonal roll, with a row of teeth about six inches long protruding from each of the sides of the hexagon, is used for pulverizing the mud, or a serrated board may be used for this purpose. This implement is sometimes used instead of the plough or *chankol*. The teeth turn in the weeds and render the mud soft. It is not suitable for use on land with deep mud or with many weeds. On the other hand, it can be used with good effect on land once ploughed, or in place of the ribbed roller. It is drawn by a buffalo or ox, and on suitable land will do one acre a day.

The rake is entirely composed of wood, measures about four feet across, and is provided with a single row of teeth about nine inches long. Drawn by a buffalo or ox, it can rake $\frac{3}{4}$ acre a day. It is sometimes provided with a handle to enable the driver to press the implement into the ground. If the rake is not provided with a handle, the driver must frequently put his foot on the rake to drive it into the mud. The action of the rake is not to draw off weeds but to drag them under the mud. A hand-operated implement, very similar to the rake except that instead of teeth it is provided with a plank of wood (sometimes serrated), is occasionally used. It is employed for making the surface smooth especially just before transplanting.

Ploughing finished, the land may be left for three or four weeks. It is about this time that the planting of the nursery is completed. At the end of this period the land may be again ploughed or harrowed, the weeds that have grown since the first ploughing being turned in or drawn off and allowed to die on the bunds, or drawn into heaps to rot, and then trodden under the mud. Lumps of soil are broken down by working the land with the bare feet or with a harrow or ribbed roller. The depth of mud is a factor deciding the type of implement that should be used. Land with deep mud (and it may be anything from an inch or two to three feet deep), cannot be

ploughed with the native implement. In deep mud cutting down the weeds and treading them under the mud alone may be made to suffice. In very deep mud, such as may occur in very low-lying natural swamps, the land is cultivated merely by driving water buffaloes round the divisions till they have trodden in all weeds and have worked the mud into a regular soft consistency.

Finally, where possible, the excess water is drawn off, leaving the mud with about an inch of water covering it. The surface may be made smooth with an implement which is virtually a plank of wood yoked to an ox or buffalo and drawn over the land. In Italy the levelling is done with a *speanoni*, a long plank drawn by a horse.

The amount of cultivation and the implements used vary with local circumstances. In Japan, in areas where only one paddy crop is grown a year the ploughing is done in winter or early spring, so that the soil may be well aerated and the organic matter decomposed before planting the paddy. Where paddy is followed by winter crops, the fields are ploughed as soon as the winter crop is removed. In Burma, cattle are usually employed for ploughing. The recognized rates of working for a pair of cattle per day of six hours are one-third of an acre for ploughing or over an acre with a blade harrow (*set-htun*). In Malaya, the rate of ploughing is much less, being about seven days per acre, and three days to harrow it, up to as much as ten days to plough an acre with a buffalo on heavy land.

As soon as the land is finally prepared for planting with seedlings from the nursery, transplanting commences. Thus, one sees preparation of land and planting proceeding at the same time. Weeds grow very rapidly and it is essential, therefore, to plant out as soon as possible after final cultivation in order that the paddy shall be ahead of the weeds.

TRANSPLANTING

The seedlings in the nursery are pulled up in small bunches without regard to the amount of roots that are retained on each plant. In Hong Kong[105] and in parts of China, however, the seedlings are removed from the nursery with care by means of a sharp, flat hoe of special design. The blade of the hoe is pushed into the bed so as to lift a patch of seedlings together with the soil and the fertilizer in the immediate vicinity of the seedlings. It is to be noted that in contrast to the system obtaining elsewhere, seedlings with adhering soil are planted in the field. Sometimes seedlings for a second crop in the year are removed by hand in Hong Kong. It is recognized by the Chinese that this root pruning is advantageous

to the growth of the plant in the field. The avoidance of this for the first crop is possibly intended to retain the fertilizer applied to the nursery in close contact with the roots.

The usual practice in most countries is to pull the seedlings, tie them into bundles of convenient size for handling, the roots being rinsed in water to remove soil, and the top few inches of leaves cut off to reduce evaporation and to give rigidity to the plants, so that when transplanted the leaves do not bend over into the water. In parts of Malabar,[193] a ripening process of seedlings for the second crop is usual. The seedling bundles are arranged in a circular heap with the roots exposed for three or four days, the heap being watered should it show signs of drying out. The bundles are then left in water for a night before being planted. The object is to destroy by fermentation eggs and insect pests to which the second crop is usually subject in this region. Seedlings treated in this way are said to regain their green colour quickly and to grow better and be more free from insect pests than are untreated seedlings.

In some regions the seedlings are carried to the fields in rattan baskets so designed that air can freely circulate, thus preventing the seedlings from becoming overheated before they are transplanted. Elsewhere, the seedlings are loaded into small dug-out boats or punts and carried on the irrigation channels to the fields. In Burma, the bundles are conveyed either on sledges or by boat.

Whereas ploughing, raking, and work in the nursery is usually done by men, it falls to the lot of the women and children in most countries in Asia to carry out the transplanting, which is often done on a communal basis. A bunch of seedlings is held in the left hand, from two to six are transferred at a time to the right hand and thrust into the mud, the distance between the "hills" of plants being from four to twelve inches, depending on the variety, local conditions, and custom. Experiments in India[102] showed that the number of fertile tillers was greater with three to four seedlings per "hill" and decreased with closer planting; length of panicle and yields increased with wider spacing. On first-class land in Malaya, a spacing of fifteen to seventeen inches is usual, using a seven months' variety of paddy. Jack[122] states that when the water in the field is deeper than one foot or fifteen inches it becomes necessary to space the plants somewhat closer than in shallow water, because deep water inhibits tillering considerably. In Burma, from one to four plants per "hill" are spaced from four to eight inches apart. The optimum spacing in Ceylon[184] is four to six inches, one seedling only being placed at each point, except where there is a liability to damage by crabs, when two seedlings are planted. In view of this very close planting it is not

surprising to learn that it requires fifteen to twenty women to plant an acre a day, as compared with ten to twelve women in other countries where wider spacing is usual and the number of seedlings per "hill" is greater. In Japan, the so-called rectangular planting is often adopted in which the interval between "hills" in the rows is narrowed. The object is said to be to give the plants sufficient sunlight despite dense planting. In contrast with this careful planting, in most parts of Bhandara and Balaghat in India the bunches of seedlings are simply thrown down into the mud as the worker moves backwards.[48] In the Krian District of Perak, Malaya, the women usually employ a small two-pronged farm implement, known as *kuku kambing* (goat's hoof), to assist in transplanting. The seedlings are placed between the two prongs and thrust into the mud. It appears to be merely a "backache-saving" device. Transplanting is arduous work, but the women work with great speed and precision, and can complete an acre in from six to ten days per worker.

AFTER-CULTIVATION

With transplanted paddy little or no after-cultivation is attempted in many areas, beyond weeding by hand. This operation is easily performed if taken in hand early, as the weeds are but lightly rooted in the mud and can be drawn together and thrown on the bunds. In the extensive Central Plain of Thailand the land is so flat that bunds are rare. This paucity of bunds makes it necessary for the weeder to squeeze the weeds into bundles and impale them on sticks which project above the level of the water, where they are left to wither. In Japan,[139] however, much care is taken in weeding and cultivating after the crop is transplanted. The field is usually weeded about a fortnight after transplanting, when the seedlings have developed new roots. After stirring the soil with a long-nailed hand rake, the water is kept shallow for two or three days while the soil is hand-levelled. Weeding is repeated after ten days, but later, intervals progressively shorten and end before the plants reach the "jointing" stage.

As a preliminary to harrowing operations in Ceylon, the field is drained overnight, leaving about three inches of water. A toothed harrow, yoked to a pair of buffaloes or cattle, is then drawn over the field, returning over the same strip in the opposite direction. This operation is then repeated in the crosswise direction. Thus, the harrow is drawn over the field four times in all. It is stated that about three to four acres can be harrowed in a day. Any vacancies in the field are then supplied by transplanting from the more thickly sown patches, and any weeds are removed by hand. It is held in Ceylon

that harrowing the standing crop increases the yield by four to ten bushels per acre, the beneficial effect being due to the stimulation to tiller formation and root development caused by trampling and

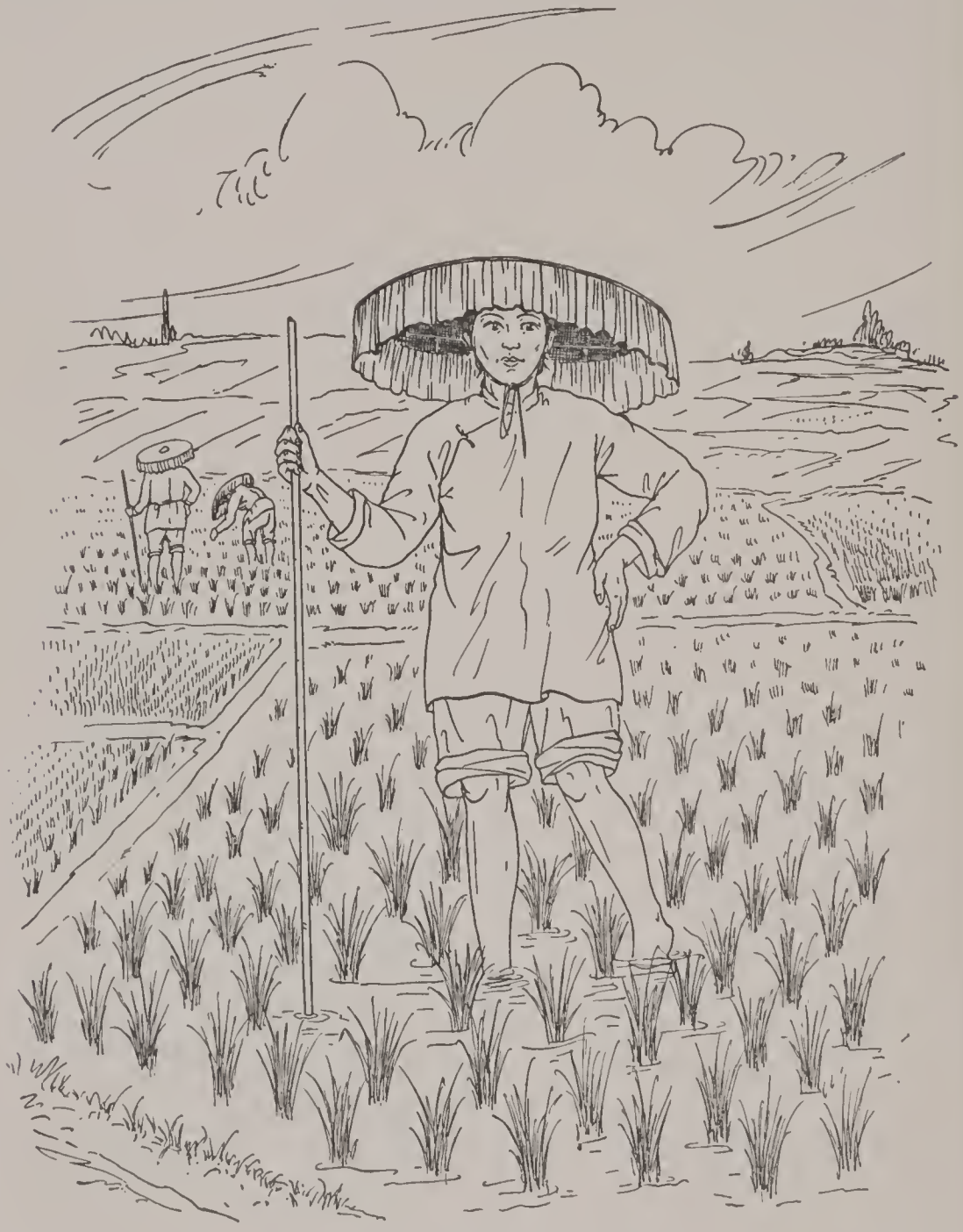


FIG. 24
Trampling down weeds

disturbance of the plants, the thinning out of excess plants, and the removal of weeds. On the day following harrowing the water in the field is reduced to about one inch, at which it is held for about five

days, when the depth is increased and should be retained at about six inches.

In China[86] the crop is usually weeded and the soil worked up twice. This is either done by hand or by means of an implement similar to a miniature harrow, consisting of a flat piece of wood just wide enough to be worked backwards and forwards between the rows, into which about a dozen curved tines two to three inches long are fixed. This is attached at an angle to a long handle.

In the United States, where broadcasting is universal, no harrowing or other cultivation of the standing crop is practised.

HARVESTING

The methods of harvesting paddy in the East are simple, but entail much labour. Vast areas under this crop are reaped by hand, either with a sickle or with other hand-operated knives. The traditional, and probably the original, harvesting implement is still widely used. It is a small knife from two to six inches long, fastened crosswise on a short stick and so held that the blade is covered by the palm. The belief is still held in many parts that the spirit of the paddy crop is offended by the rough cutting of the sickle, and will show his displeasure in the following season by causing the crop to fail, but that he will imagine the small knife in the hand to be a bird, which in fact it is made to resemble, and will therefore not visit his wrath on the offenders. This implement is well known in Malaya, where it is given the name *pisau penuai* (the harvesting knife), in Java, and also in the Philippines, where it is called a *yatab*, but its use is gradually giving way to the sickle. Using the small knife, the harvester bends the finger round the stem of the plant and draws the ear on to the knife, which severs it from the stalk a few inches below the collar. When a few heads have been cut and retained in the cutting hand, they are transferred to the left hand, until a large bunch is obtained. This is then placed in a basket for removal from the field. The chief advantage of this laborious method is that the maximum crop is obtained from badly lodged or from unevenly ripe areas.

Where the *yatab* knife is not used—and this includes all India, Burma, Indo-China, and Japan—the sickle is employed, and this implement appears to be gradually replacing the *yatab* in Malaya and Java. The sickle varies in shape in different countries, but it is essentially the same, being the familiar shape and usually having a serrated cutting edge. The crop is cut with about two feet or more of straw and sometimes, after preliminary drying in the field, is taken to the threshing floor. Occasionally the crop is cut with a sickle about

six inches from the ground and when dry is made into small round stacks, built on old ant hills or on other situations which are unlikely to flood. The stack may have a diameter of about nine feet and a similar height. The stacks are protected from rain by a thatch of sago palm leaves. The paddy remains in the stack for two or three months. Stacking of paddy is common in Java and may be seen occasionally in Malaya, where it was probably introduced by Javanese settlers. The maturing of the grain in stack facilitates threshing, as the grain comes off more easily.

THRESHING

Threshing of paddy separates the grain with its adhering husk or glumes from the stalk. Generally throughout the East the paddy crop is threshed as soon as it is harvested; occasionally, as condition of the crop demands, after a short period of sun-drying.

In Burma the sheaves are brought to threshing floors where they are laid in the sun to dry. The sheaves are laid two or three deep round a stake with the heads towards the stick. Buffaloes or kine are then driven slowly round to trample out the grain. Less commonly the threshing is done by beating the sheaves against a block of wood.[202] In Malaya, the sheaves are threshed on or adjacent to the paddy-fields. A tub about the size of a half-barrel is used. Inside the tub rests a ladder with rungs about four inches apart. The sheaves are beaten against the ladder two or three times, causing the grain to be removed from the ears and to fall into the tub. A screen is placed round the tub to prevent the scattering of grain.

Much paddy is also threshed by foot. When this is done, the workers treading out the paddy prefer the ears to be slightly damp as they say it is less injurious to the feet. Awned paddy is distinctly unpopular if it has to be threshed in this way.

Awners (*ebarbenses*) are used in Italy to remove the awns. The machine is described[249] as consisting of two metal cylinders on the same axis (generally vertical, but sometimes horizontal). The inner cylinder rotates around the fixed outer cylinder. Both cylinders carry metal tines which cross each other, one set with the points inwards, the other with points outwards. The distance between the two sets of teeth is sufficient to permit passage of the grains downwards while the inner cylinder is rotating, the awns being removed by the impact without the ends of the grains being damaged. The awns are then removed by a fan or aspirator.

Copeland[51] gives the following technique for threshing awnless paddy as practised in Leyte in the Philippines. "A platform, eight

or ten feet high, with bamboo floor with cracks between the slats, is erected. A rope is stretched above the platform; to this the workers hold with their hands while they work the rice with their feet. The

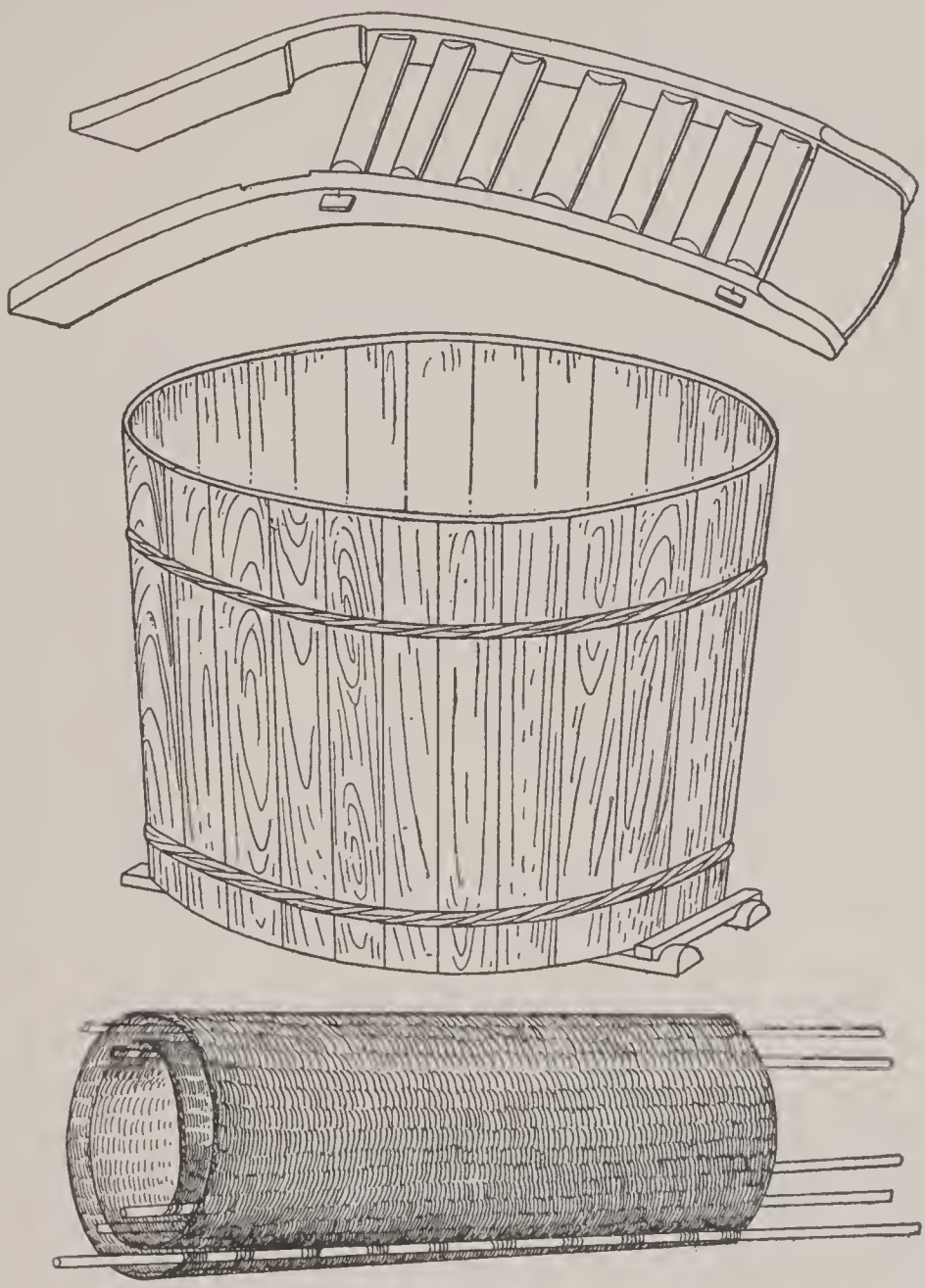


FIG. 25

Implements used in threshing paddy.

1. Threshing ladder 2. Threshing tub 3. Threshing mat

grain falls through the cracks, is winnowed by the wind, and collects, clean, on a mat on the ground. An efficient worker separates as much as fifty *cavanes* (about 500 lb.) a day in this way. The remark-

able feature of this method is the removal of the grain as fast as it is separated from the straw, so that the worker sees constantly what remains to be separated."

WINNOWING

The native method of winnowing is of the simplest. It is performed by shaking backwards and forwards paddy placed on a flat tray of plaited bamboo or rotan finished off with a lip about an inch high. The paddy is shaken and tossed with a twist of the wrists,

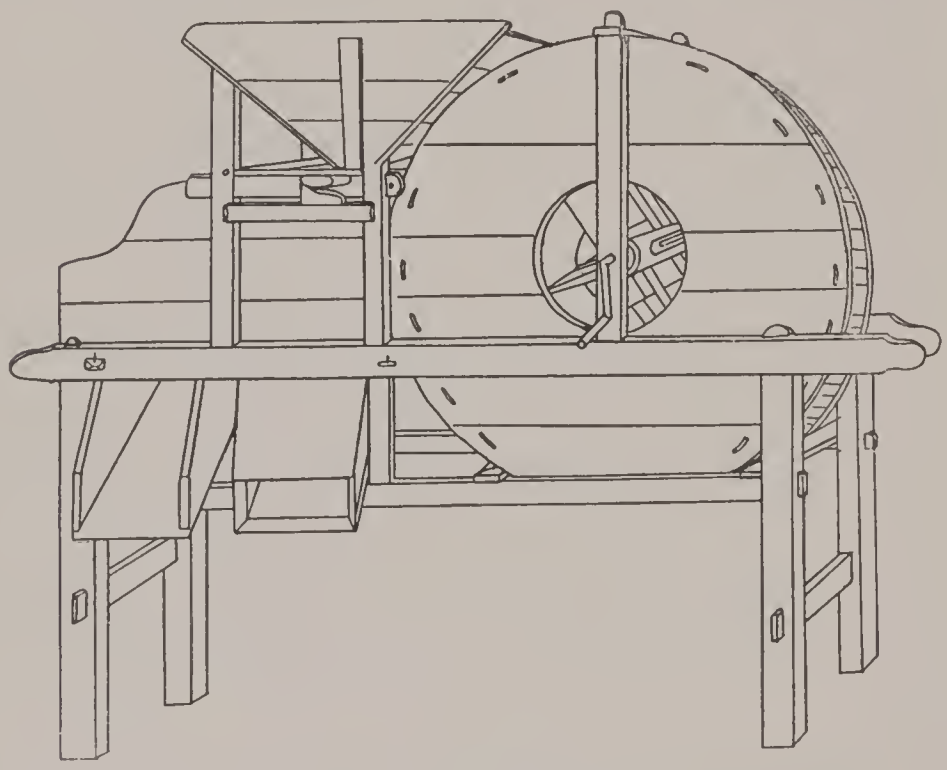


FIG. 26
A hand-winnowing machine

which has the effect of working the empty husk, light grain, and chaff to the edge of the tray furthest removed from the worker. As a result of long practice, the worker is able to throw over the edge of the tray the outer portion, which consists of chaff and dust. Then, standing at the windward edge of a mat, the worker holds the tray above the head, gently shaking the paddy from the tray, so that the good seed falls on the mat and the husk and chaff is carried away by the wind. Women generally perform this task and they may frequently be heard calling the wind by a kind of yodel, or calling the spirit of the wind by name.

Paddy is also winnowed by suspending a bamboo sieve of one-half

inch mesh from a tripod about six feet high. Paddy is placed on the sieve, which is then gently rocked. The wind carries away dust and husk and the cleaned grain falls to a mat placed below the sieve.

Hand-winnowing machines are coming into favour in some areas. In this machine a draught is created by turning a handle which operates a fan. Paddy is fed into a hopper from which it falls into a draught created by the fan. The rate of feeding the grain is regulated by a wooden shutter. The draught carries off the chaff, and the clean grain falls and is collected separately.

The winnowing of paddy before sale to the mills is insufficient to meet the requirements of the miller. On arrival at the mills the paddy is subjected to further sieving and winnowing to remove immature grain and extraneous matter such as sticks, straw, sand, stones, and pellets of mud. Even in a consignment of fair average quality the matter removed may amount to 2 to 5 per cent by weight of the total.

Shakers or shaking riddles remove the larger impurities and the grain then passes over aspirators consisting of fans so arranged as to draw air through a thin curtain of paddy, thus carrying away the lighter deleterious matter.

DOUBLE-CROPPING SYSTEMS

In many parts of China, Japan, Ceylon, parts of India, and elsewhere, two or even three crops of paddy are removed from the land annually. Because there are two monsoons during the year, many of the paddy areas in Ceylon are cropped twice annually. In hilly regions such as Priangan and Kedu in Java, where much water is available throughout the year and paddy cultivation is therefore less dependent on the season, three harvests in two years, or two harvests in one year, are obtained.

Writing of the double-cropping paddy areas of China, Buck[33] states that the larger cultivated areas are in flat irrigable valleys, scattered from Lungchow, Nanning, and Ishan eastwards at an elevation of 500 to 1,000 metres above sea-level. The Canton Delta, about 7,000 square miles, is the most important, and is considered the most prosperous in the whole area, and the most intensely cultivated. The area is practically frostless, the mean temperature being 57° in February, the coldest month, and 84° F. in July, the hottest month. A well-distributed rainfall of about 69 inches is experienced, with rather high humidity.

The soils of the area he describes as being chiefly red soil of the laterite type, podzolized Old and Young Red Earths on the eastern

two-thirds of the area, and Older Red Earths on the western part. Both types of soil erode easily, are badly leached, and require heavy fertilization, for which reason large areas remain uncultivated. In the valleys modification has occurred through centuries of paddy cultivation, resulting in a podzolized soil of a different and more productive character. The yield of rice in this double-cropping area of China is said to be low.

Gourley[86] states that from Manchuria to south of Shanghai only one crop is grown per annum. From this point to Foochow two crops are grown by interplanting, and south of Foochow and in central China two consecutive crops are grown. When two crops are obtained by interplanting, this is achieved by means of the use of one early and one late variety of paddy. Both varieties are sown in the seed bed at the same time, about the middle of April. The early variety is transplanted in the middle of May in rows eighteen inches apart, and a fortnight later the late variety is interplanted between the rows. The early crop is harvested by the end of July. The second crop, the growth of which has been retarded by the shade of the first, is then able to develop rapidly and is harvested at the end of October.

In Hong Kong[105] there is a choice of five varieties of paddy for the first crop, the maturation period varying from 95 to 125 days, and six varieties for the second crop, with maturation periods varying from 100 to 125 days. Seedlings are retained in the nursery for fifteen to forty days for varieties cultivated for the first crop, the length of time in the nursery depending on variety. For all second-crop varieties the seedlings are in the nursery from twenty-five to thirty days.

In order to obtain two harvests a year there must be strict observance of the time-table for planting and cultivation. In Hong Kong, for the first crop, the nursery is planted from early March to early June, and the crop is harvested about mid-July. For the second crop, the nursery is planted at the end of June or early July, and the crop reaped in November. In this way advantage is taken of the rainy months, which are from May to September. During this period between sixty and seventy inches of rain may be expected out of a total annual rainfall of between eighty and ninety inches. Between November and March the land is frequently utilized for the cultivation of crops other than paddy.

A top dressing of fertilizer, weeding, and cultivation are usually carried out together about a month after transplanting, when the more prosperous cultivator will broadcast about 75 to 100 lb. peanut cake powder and 25 to 50 lb. ammonium sulphate per acre.

The less well-to-do cultivator will be content to use about 600 lb. per acre of dried cow dung instead. Before broadcasting the fertilizer the field is drained and immediately after its application the weeds are trampled into the mud and the paddy roots pressed deeply into the mud at the same time. In some districts a wooden board with nails protruding on the lower surface is pushed in between the rows of plants to assist in packing the mud round the seedlings. The field is left to dry for a period of three to five days, the belief being that this enables more effective absorption of nutrients when irrigation is resumed. Sometimes weeding is carried out twice during the growing period and two applications of fertilizer are given.

From the time when the lower part of the stem begins to swell no one is permitted to walk in the field for fear of interfering with the formation of grain.

The average yield of paddy is stated to be about 1,600 lb. per acre for the first crop and 2,000 lb. for the second crop, so that the two crops give an average yield of about 3,500 lb. of paddy per acre per annum.

Double cropping of paddy is quite common in Japan, where cultivation has followed the pattern of the Chinese methods. It is chiefly to be found on the island of Shikoku, the shores of Kinki and Tokai districts, and in Formosa and Okinawa. In the two northern provinces of Formosa—Taihoku and Shinchiku—where rainfall is fairly evenly distributed and irrigation facilities are ample, about 80 per cent of the fields grow two paddy crops a year. The proportion of double cropping decreases the further one goes south. In south Formosa, the rainfall is insufficient to allow two crops annually, the single crop being grown about May and harvested in November.

In the Kochi Prefecture of Japan, the first crop is sown in the nursery in late March and transplanted thirty days later, the harvest being reaped early in August. The second crop is sown in the nursery in July, transplanted as soon as the first crop is reaped, and ripens in about ninety days. An early variety is grown for the first crop and a late variety for the second crop. The yield of the second crop is stated to be about 60 to 70 per cent that of the first crop.

The main limitations to an extension of double cropping a paddy is availability of water, temperature, and a suitably dry season for harvesting. Under monsoon conditions common over most of the paddy-growing areas of south-east Asia, water is not available to permit of the cultivation of paddy beyond a period of about seven months in the year; consequently, economic production must depend on a single crop of a long-term maturation variety to cover the period rather than the employment of two short-term maturation crops.

Burgess,[34] writing of the Central Plain of Thailand, states that the inter-season rainfall in that country is scanty so that a second crop cannot be grown. He adds that some of the more recently completed irrigation schemes are designed to supply water independently of the rainfall, the ability to do so depending on the level of the water in the stream across which the barrage has been erected, which in turn is governed by the rainfall in the catchment area. The authorities are hopeful that in the area served two crops of paddy per annum may be realized.

Experimental data is far from complete concerning the relative merits of a single long-maturation crop per annum or two crops of shorter maturation period. It is common experience that the longer the maturation period the heavier the crop. Whether two crops of shorter maturation period will produce a heavier crop than one crop of long maturation period probably depends on local conditions. From the economic standpoint, one must remember also the very much greater cost of producing two crops per annum as compared with one crop. It is possible that as irrigation schemes are improved and perfected in South-east Asia, reconsideration may be given to the economics of producing two crops a year. In the meantime, the best course would appear to be the planting of varieties of paddy with the longest maturation period possible in conformity with the expectation of sufficient water to irrigate the crop during its period of growth.

FORTUITOUS PADDY CROPS

In some areas it is customary to obtain a ratoon crop of paddy. Certain varieties are suitable for this purpose, ratooning being very largely a varietal character. The first crop is cut before all the green has left the straw, the land is again irrigated, and axillary buds then develop at the lower nodes. In exceptional cases a satisfactory crop is obtained, but usually it is very light. The system is not recommended, as it greatly increases the incidence of insect pests.

Under suitable climatic and soil conditions, and with adequate water, a second crop may be obtained from seed dropped during the harvesting of the paddy crop. This system is largely adopted in British Guiana. The method cannot be recommended, as subsequent paddy crops are likely to be adversely affected as a result, due in particular to the delay in preparation of the land, to a marked increase in weed growth, and the greater incidence of insect pests. Drop-seed cropping in British Guiana is largely responsible for the increase of the "red rice" in the main crop throughout the colony.

ROTATIONS

The subject of the rotational cultivation of paddy is intimately connected with soils and manuring. Ordinarily, it is an accepted principle of agricultural practice that an annual crop cannot be produced economically continuously on the same land. But such is the nature of the paddy crop that this continuous cropping is possible, and has in fact been in vogue for hundreds of years in parts of Asia, usually without any systematic manuring. Crops are now sustained at the lowest level of production. In certain parts of Asia, notably in China and Japan, continuous cropping with paddy is not usually practised, two crops being obtained in the summer months, followed by winter crops, such as sweet potatoes, tomatoes, and green vegetables. Lord[143] observed in the neighbourhood of Saigon in Indo-China that many of the fields from which the paddy crop had been removed about two months previously were being cultivated with tobacco. This catch-crop was being irrigated from wells situated in the fields.

In well-drained, terraced fields in Ceylon, where the soils are of a light texture, vegetables are grown for one season, and since these rotations commenced, the paddy crops have shown marked increases in yield. In a recent report from the Malayan State of Kelantan,[12] it is stated that as a direct result of an off-season crop of vegetables there was a 45 per cent increase in yield of the subsequent crop of paddy.

In many parts of Asia, however, the semi-aquatic conditions which prevail throughout the year, or the nature of the soil when it dries out, preclude the cultivation of any crop other than paddy. Most of the paddy land of Lower Burma, for instance, is unsuited to the cultivation of any other crop than paddy. The possibility of establishing a rotation of crops on such lands as these must therefore be ruled out, and one comes to the alternative—the simplest form of rotation—a crop of paddy followed by a fallow, or two or three crops of paddy followed by the fallow period. This system is not unusual in the East and is also seen in the United States. In the wet tropics uncultivated land does not remain bare for long. Weeds, grasses, and frequently secondary jungle take possession and soon cover the land. While this system appears to serve its purpose, it cannot be considered as ideal, for it does little to increase the manurial content of the soil, and it encourages noxious weeds and insect pests.

Paddy cultivation in the United States has been able to develop unhampered by the traditions and prejudices inseparable with attempts to institute new methods of cultivation in Asiatic countries,

In California[79] a rotation of three crops of paddy followed by spring or summer ploughed fallow on which wheat or barley is sown in the autumn, after which paddy is grown for one year, is usual in some districts. Another method used is to alternate a paddy crop with a fallow. Some growers do not fallow but leave the land uncropped and uncultivated until it is prepared for paddy in the following spring, and such lands are often pastured. Experiments in Louisiana[125] showed that in a four-year rotation fertilizing cotton or stubble pasture did not increase the yield of the following paddy crop, but paddy after stubble pasture yielded 7·4 bushels per acre more than after cotton. The rice yields on a ten-year rotation of paddy following cotton average 32·1 bushels per acre, following native pasture 47·1, following maize and soya bean 45·6, and following improved pasture 48·7 bushels per acre. On land continuously in paddy for forty-nine years, the yields were 24·5 to 32 bushels per acre, depending on climatic variations rather than on fertility.

In Texas, the rotation of paddy with sesbania gave the highest yield. But cultivated crops in rotation with paddy are often unprofitable in the United States. In Louisiana and Texas it is usual to grow one or two paddy crops and then pasture the land for one to three years before planting paddy once more, cattle being put on the pasture. By this method rice yields have been much increased and it has been possible to increase the rate of stocking.

In the Murrumbidgee Irrigation Area of New South Wales a three-, four-, or even six- to seven-year rotation has been developed for paddy, with cereal crops such as wheat and oats, and with temporary pastures on which fat lambs are successfully raised. Under this system, the soil has yielded prolific paddy crops, with an average of 1·8 tons of paddy per acre.[111]

In Indonesia, satisfactory control of water and a suitable soil for dry-land crops favour rotation of paddy with dry-land crops, and on much of the land paddy is rotated with such crops as maize, soya beans, and groundnuts. In sugar-producing areas government conditions of land tenure compel a rotation of paddy with sugar.[143] In parts of the Philippines, also, paddy is successfully grown in rotation with sugar.

The rotation of crops with paddy is more usual in countries where there is a winter season, paddy being grown in the summer months and other crops—usually food crops—in the winter. In Italy[196] rotations are usually practised. Around Vercelli, one crop of cereal such as wheat or oats is followed by one or two years of pasture, after which paddy is grown for three or four years. In regions where clay soil predominates and where drainage facilities are lacking, as in

Bologna and Montana, paddy is grown but once in the rotation. It is now considered that the continuous cultivation of paddy reduces yield owing to defective soil aeration and consequent disturbance of the microbiological balance in the soil. A further objection to continuous cropping is that it is said to result in an increase of malaria. The rotation may be from four to eight years. The typical four-year rotation in Italy provides for maize, hemp, or beetroot in the first year, followed by wheat in the second year, pasture in the third year, and paddy in the fourth year. Rotations of longer duration usually allow for two to three years in pasture, while the eight-year rotation may be: first year, wheat, rye, or maize; second to fourth year, pasture; fifth year, wheat, rye, or maize; followed by three annual crops of paddy.[250]

It has been pointed out[283] that the advantages of a rotation of a grass ley with dry cereals is now in principle accepted widely and its extension to include paddy may hold out great possibilities as it may enable animal husbandry to be incorporated into a rice economy under tropical conditions. "It is uncertain," adds this authority, "how far this would be practical politics in unregulated peasant agriculture, although even here controlled rotation of rice with sugar cane, pulses, and dry grains on communally owned peasant land has long been a feature of the system devised many years ago by the Dutch in Java, while in north Malaya cattle and buffaloes are pastured in rice-fields during the interval between two crops."

The rotation of paddy with other crops implies an adequate control of irrigation and drainage throughout the year. This control is obtained in Spain, Italy, and New South Wales, where the rotation of paddy with temporary pasture and dry-land crops is successfully operated, and the yields of paddy are high. Before 1877 the rice yields in Italy were little if any higher than those in tropical countries. It was the influence of the Cavour canal resulting in the introduction of rotations that went far to increase paddy yields in that region.

The inadequate control of irrigation in most parts of the paddy belt of Asia militates against the development of crop rotation, coupled, in many cases, with the very stiff clay soil. Where control of water is possible and the soil is not too heavy, rotations are possible and are sometimes practised. In the Jaffna District of Ceylon, for instance, tobacco, chillies, green gram, gingelly, vegetables, and sunn hemp are rotated with paddy, the crops being irrigated from wells situated in the fields. It would appear, therefore, that the development of rotations in Asia might be advantageous, but the system is unlikely to make much headway in the absence of good water control.

RED RICE

In the United States red rice is considered the most serious weed pest which, unless eradicated promptly, soon practically takes possession of the land. Red rice differs from white rice in that it has a red instead of a brown kernel coat. Its presence detracts from the value of the product as marketed, while if the rice is milled to eliminate the red colour, the milling must be so close that a quantity of rice is broken in the process and the percentage of bran is increased.

Red rice is spread largely by using seed that contains red grains. In the southern states it is said to shatter easily, and like many other weeds has the ability to retain its viability in the soil for several years.

Official American publications point out that red rice may be the result of natural crossing "because all the plants of the first hybrid generation and three-fourths of the second generation have the red kernel coat. The proportion of red rice rapidly increases when crossing between red and white varieties occurs. The short-, medium-, and long-grain red rice seeds and kernels, which are at times observed in rough and brown rice and in the fields, probably originated as a result of natural crossing between the cultivated varieties of these types and red rice. Some of the red-rice types that appear as a result of natural crossing are seemingly identical in all respects with the cultivated varieties except for the red kernel colour. It is not possible to locate and pull these plants in the field."

Methods of control in the southern states include the avoidance of seed paddy containing red seeds, removal of such plants in the field where this is possible, mowing, summer cultivation, and pasturing. Price discrimination imposed by millers has made growers more careful to protect their crops against red rice. By this means, paddy brought to the mill usually contains not more than about 1 per cent red rice.

Many of the cultivated varieties of paddy in Asia have a red pericarp. If the crop is destined for local consumption this is of little importance; the insistance for rice free from red grains arises in large-scale production to supply world markets, where great stress is made on appearance.

The following observations on red rice were made by the writer during an investigation in British Guiana. Red rice in that country almost certainly consists of one or more varieties and numerous crosses of these with the white-grained varieties. The rate of cross-fertilization is stated to be not more than 2 per cent. Red-grained

plants usually have all the external characteristics of the white varieties amongst which they grow, while the fact that the grain is not dissimilar to the white varieties renders it impossible to separate red from white paddy in the mill by mechanical means.

Red rice is extremely difficult to identify in the field; it can, in fact, only be done at flowering time and when the grain is in the early stage of formation. "Rogueing" of the crop for the eradication of red rice therefore entails the employment of a large number of experienced men for a short period. It is only practicable in growing paddy for seed purposes.

The incidence of red rice is less marked in areas where the crop is transplanted from seedlings than where the seed is broadcast or drilled. This is probably due to the cultivation of the land being more protracted and final preparation being completed just before transplanting. It is probable, therefore, that most of the drop seed has germinated and been destroyed before the land is planted out. Furthermore, the taking of a drop-seed crop is less frequently practised in areas where transplanting is the rule.

Red rice is considered to be the most serious pest of paddy in British Guiana. It causes considerable loss of yield due to its tendency to early shattering in comparison with the main crop, thereby not only decreasing the harvested crop but also infesting the land with seed which will either grow as a drop-seed crop or may develop with the subsequent planted crop. Furthermore, it is stated to retain its viability in the soil for a period of years, but of this there appears to be no statistical evidence. In the mill further losses result from the presence of red rice due to extra milling required to remove the red outer layers from the rice, and by loss of quality and grade of head rice due to its reddish tinge which cannot be entirely eliminated.

The following measures are recommended to control the incidence of red rice in the field:

(*a*) No ratoon or drop-seed crop should be allowed, and where the crop is grown from broadcasted or drilled seed only one crop per year should be taken.

(*b*) Only properly selected and rogued pure line seed should be sown. It is, however, useless to use pure-line seed unless steps have been taken to eliminate the red seed from the land.

(*c*) Early ploughing after harvest to encourage germination of drop seed which should then be controlled by grazing cattle.

(*d*) Deeper ploughing is said to discourage development of red rice in the soil.

(*e*) Thorough cleaning of harvesting machines before entry into a field.

(*f*) It may be necessary to rest each field for one year in four; thus, the rotation might be three years paddy followed by one year fallow, during which cattle would be grazed on the land.

(*g*) Early ploughing after harvest should be immediately followed by two or three weeks of flooding. Paddy seed rots if placed in the soil on flooded land.

WEEDS

Paddy land is particularly suitable for the development and spread of a number of aquatic and semi-aquatic weeds. Of these, perhaps the most universal are various species of Cyperus, or umbrella plants, commonly known as sedges, some of which are annuals while others are perennials.

The penalty for broadcasting paddy is the increase in the menace of weeds. In Asia, where paddy is usually transplanted, adequate opportunity occurs for the suppression of weeds, the land receiving its final cleaning just before transplanting. The seedlings at transplanting may be anything up to forty days old, and they quickly establish themselves in the field. The crop of standing paddy is weeded by hand from time to time. The crop develops and tillers quickly and is therefore soon in advance of weed growth so that the latter can no longer compete with the crop. Where paddy is broadcasted, crop and weeds develop in active competition and weeding is impossible. Where the paddy is drilled there is limited opportunity for weeding between the rows. It is to be noted that weeds assume increased importance in those parts of Asia, such as parts of Ceylon and India, where broadcasting is usual.

In California various species of Cyperus are common. Perennial forms grow on the bunds and poorly drained abandoned land. Where they occur in the fields, improved drainage and good cultivation is said to rid the fields of them. The annual forms are found amongst standing paddy, especially where the stand of paddy is thin. It is said to be most troublesome in seasons preceded by wet spring weather. In Ceylon, *Cyperus iria* and *C. dehiscens* appear in most paddy-fields soon after the paddy is sown, flower in about a month, and may produce a second crop in one season, seeding being very prolific. The weed flourishes best on insufficiently irrigated land.

Typha species, the cattails, are common in the paddy-fields of Asia and in the Western Hemisphere. The cattail is a perennial which spreads by seed and by creeping root-stock. Seeding is prolific and is distributed by wind and water.

Numerous species of water grasses, *Echinochloa*, are common to paddy-fields everywhere, and in the United States are considered a serious pest. The varieties are placed under four groups:[79]

(1) The early red varieties, which grow from $1\frac{1}{2}$ to $2\frac{1}{2}$ feet high, stool heavily, and have small stems with rather short, compact heads and small seeds. These varieties have purplish-green stems, leaves, and seeds, and mature and drop their seed before the rice is headed.

(2) The mid-season varieties, which grow from 3 to 6 feet high, stool quite heavily, and have rather coarse stems with comparatively long, loose heads and mid-sized seed. These varieties usually have purplish-green stems, leaves, and heads, the purple colour being less pronounced than in the early varieties. They mature and drop most of their seed before the rice crop is fully headed.

(3) The late white varieties, which grow from 2 to 5 feet high, stool heavily, and have rather coarse stems with comparatively large, compact heads. One variety has large seeds, while another has much smaller seeds. The late white varieties do not shatter as readily as the two groups just mentioned, and much seed is present in the threshed rice. The heads of the late white varieties are yellowish-green and usually mature before but often with the paddy crop.

(4) Other late varieties, which grow from $2\frac{1}{2}$ to 4 feet tall and stool heavily, have mid-sized stems with comparatively compact heads and mid-sized to large seeds. One of these varieties has short, stiff, red beards, and another is beardless. The plants' heads are the same colour as the rice. They usually mature at the same time as the paddy crop.

The water grasses, or barnyard grasses, are annuals, and most of them tiller abundantly and produce much seed. The white water grasses do not shatter as the other forms, and much of the seed may therefore be harvested with the paddy crop.

Where not numerous, control may be effected by hand weeding, a process which, however, is usually too costly. Control by continuous submergence is now extensively accepted as the most effective method. In California it is particularly effective in the control of the early and mid-season types, but this method does not check the growth of the white water grasses. Species of *Aeschynomone* and *Fimbristylis* appear to be common in paddy-fields in various parts of the world. Among other weeds reported from California are the spike rush (*Eleocharis palustris*), a perennial which establishes itself in places where cultivation and drainage are poor; the water plantain (*Alisma plantago*), the presence of which has been on the increase during the past few years; arrowhead (*Sagittaria latifolia*) favours lower situations and thin stands of paddy, and tends to increase as a serious pest, and *Leptochloa fascicularis* may also be found in low land, while *Ammannia coccinea* or redstem is found in shallow

drainage ditches and often in paddy fields, especially where the stand is thin. The creeping perennial weed, joint grass (*Paspalum distichum*), spreads rapidly by rooting at the nodes and is difficult to eradicate. When growing in ditches it tends to impede the flow of water unless the ditches are frequently cleaned. Water hyssop (*Bacopa rotundifolia*), bulrush (*Scirpus fluviatalis*), canary grass (*Phalaris paradoxa*) and *P. brachystachys*, crabgrass (*Digitaria sanguinalis*), *Aster exilis* and *Bromus secelinus* are also mentioned in connection with paddy cultivation in California. To these may be added a number of varieties more commonly met with in the southern states, including *Caperonia palustris*, *Sesbania macrocarpa*, *Diodia teres*, *Sphenoclea zeylanica*, *Commelina virginica*, and *Polygonum acre*.

The beautiful water hyacinth (*Eichornia crassipes*) is found in many parts of Asia, including India, Malaya, Ceylon, south China, and Java, and also in America. It is often a troublesome weed, impeding the flow of water in rivers and irrigation channels and causing flooding. The plant floats in deep water and roots in swamps. Propagation is by seed and by stolons. The latter arise from the plant base and bear suckers which become independent when the runners break. Swellings at the base of the leaves act as floats and the roots as ballast. In this way the plants are carried long distances by wind and current, especially in times of flood. When the water subsides they settle down as dense carpets and root in the mud. The seed only germinates when desiccated and germination may therefore be delayed for many years, a fact which accounts for reinfestation in areas that have been cleared of the weed, so that long surveillance is essential to keep the weed in check. Mechanical methods of control have hitherto been considered necessary as no completely satisfactory chemical control has been discovered. Recently, however, in Malaya[124] a 1/60 and a 1/100 emulsion of ethyl ester of 2, 4-D used against water hyacinth in still water, applied at the rate of 160 gallons per acre, gave good control. The heavier dosage gave complete kill in three weeks, the 1/100 solution taking a month for complete kill, but spot spraying was required to kill off individual plants.

Isachne australis is common in Eastern paddy-fields, *Coix gigantea*, the giant adlay, is reported as a paddy weed from Ceylon, as are also *Ischaemum rugosum*, *Asteracantha longifolis*, and *Fimbristylis miliacea*. Failure to weed in Ceylon is said to cause an average loss of 20 to 25 per cent of the crop.

In India, and indeed in most parts of the East, various wild varieties of paddy are associated with paddy cultivation. In North Sind much damage is occasioned by a thick algal growth causing the water

38. Winnowing paddy, South India

39. Threshing grain in Egypt

40. Paddy awaiting sun-drying before storage, British Guiana

41. Drying paddy at the millyard. Labourers are raking the paddy to dry in the sun, Malaya

to become stagnant and partially strangling the paddy. It may be controlled by drawing a bag of copper sulphate through the water, using 16 to 20 lb. per acre. The scum dies off and settles and leaves clear water in from three to five days. The scum does not reappear with subsequent irrigation.

Copeland[51] has drawn attention to various species of panicum which are stated to have been introduced into paddy-growing districts in Italy with imported seed, *P. phyllorhyzoide* and *P. Crus-Galli*, it is stated, being the worst weeds of Italian rice.

The land of the Central Plain of Thailand is baked hard and is cropless for most of the year, but it may be under considerable depth of water during the paddy season. The weed flora is therefore sharply divided into dry- and wet-season phases, both being characterized by an abundance of annuals. During the dry season the land is covered with grasses, species of Sporobolus being dominant. The flood water destroys these and they are then replaced by aquatics, mainly annual and perennial sedges and rushes, and annual weeds the seeds of which lay dormant until the land became sufficiently wet. *Ottelia alismoides*, *Sagittaria sagittifolia* (arrowhead), and species of *Mimulus*, *Monochoria*, and *Utricularia* are common. Weeding in Thailand is not usually practised, the depth of flood water usually making weeding impossible in many areas, and also flooding out all but the aquatic weeds. Conditions in Burma are very similar. Most of the paddy is transplanted, and preliminary cultivation is sufficiently thorough to reduce the trouble from weeds.

Hand weeding is usual in the Philippines, the chief weeds being the perennial grasses *Leersia hexandra* and *Imperata cylindrica*, various sedges—which are the worst weeds—and *Monochoria hastata* (Pontederiaceae), which resembles water hyacinth but is always anchored.

In China, Japan, and Korea, thorough preliminary cultivation and frequent weeding reduce weed trouble, while the cleansing of the bunds and the planting thereon of soya beans also assist in reducing loss of crop by weeds.

In Egypt, soils in the irrigation area are liable to become saline. When this is the case paddy is grown, the growing crop being treated with successive flooding and drainage to rid the soil of salinity (see page 35). The test crop for salinity after removal of the paddy is a weed, *Panicum Crus-Galli*, which is deliberately planted with this object. If this weed will not grow the land must be subjected to further washing. Needless to say, the weed is liable later to become an embarrassment.

New and very potent selective weed-killers may do much to rid

paddy-fields of weeds, but as yet knowledge of their behaviour in this connection is incomplete. Attempts have been made in Malaya[4] to control weeds by the use of these selective herbicides. The following were tried: Y.F.1541 (Fernoxone)—2,4-D sodium salt; Methoxone—4 chloro-2 methyl phenoxyacetic acid; Barweed —2,4-D amine; Weedone—2,4-D ethyl ester. While broad-leaved plants were killed and the growth of sedges was checked sufficiently to ensure some control during the rest of the season, it was considered that efficient water control and a close even stand of paddy is the only sound method of reducing hand weeding. In the United States, Ryker[222] reported that Sinox and 2,4-D were effective in controlling Mexican weed (*Caperonia castaneaefolia* (L) st. Hil) when treated before flooding and when the water coverage in the field after treatment was satisfactory. 2,4-D was superior to Sinox when applied one or two weeks before flooding, but neither was effective when treatments were made three weeks after flooding. Sinox was not as effective as 2,4-D in the control of indigo (*Sesbania macrocarpa* Muhl.) and curly indigo (*Aeschynomene verginica* (L) B.S.P.). Indigo was killed at an early stage of development by 2,4-D, but early indigo was more resistant to the chemical and for satisfactory control two applications made three weeks apart were often necessary. Dusting was as effective as spraying for the control of Mexican weed and indigo and was more effective for the control of curly indigo. Large increases in the yield of rice were obtained when weeds were controlled.

It is reported that in Texas aeroplane applications of 2,4-D as dusts and sprays, using water and oil solutions, gave effective control. Oil sprays caused slight temporary injury. The dusts, except isopropyl ester dust with oil, which gave effective control, became washed off by rain six hours after application and did not seriously damage the weeds (Mexican weed and tall and curly indigo). In field trials, the tricthanolamine, ammonium, and sodium salts and the butyl ester at rates up to 1 lb. per acre in fifty gallons of water, applied three weeks after emergence, gave good control. Yields were about the same as those of control plots except with ammonium salt and butyl ester at 1 lb., which depressed yields. All treatments six weeks after emergence gave good control, except with butyl ester at $\frac{1}{4}$ lb. per acre, and significantly increased the yields, as did also the triethanolamine salt eight weeks after emergence.

Douglas[71] refers to ridge cultivation which has been adopted in parts of Italy. "In this system," he states, "rice seed is sown on the crest of the ridges under the least possible depth of water, while the greater depth of water in the furrows undoubtedly helps to drown

the weeds. Moreover, by this method it is relatively simple to remove the weeds from the furrows without damage to the rice." The weeds that would be killed would probably be the dry-land weeds, which would in any case be destroyed by inundation. The ridging of land for cultivation of other crops between the paddy seasons is common. Tidbury[253] states that results of experiments in Zanzibar indicated that increased yields of rice were obtained if after the rice harvest the land is thrown up into ridges and planted with other crops. He does not mention the effect, if any, on weed growth.

To sum up: One cannot yet state whether herbicides will prove successful in killing weeds in paddy fields. It may be that it will prove successful, but may also kill the fish, which in many parts of Asia are a valuable subsidiary source of income. Hand weeding remains the most efficient means, while transplanting enables weeds to be kept under control. Water control may be used to control weeds, and there should be one period in the year when the land is completely dry. Time and depth of ploughing are also factors affecting the incidence of weeds.

Chapter IX

CULTIVATION OF DRY-LAND PADDY

Advantage of Dry-land System—Primitive Methods of Cultivation—Japanese Methods—Dry-paddy in Kelantan—Philippine Systems—Dry-land Paddy in Jamaica—South America—Cultivation Elsewhere—Conclusions.

ADVANTAGE OF DRY-LAND SYSTEM

DESPITE the fact that it is the oldest form of paddy cultivation, non-irrigated or "dry" paddy appears to have received less attention than it deserves both from cultivators and from investigators and writers on the subject of the rice industry.

The potential value of dry-land paddy cultivation does not depend on the fact that it is the original method of cultivation of the crop. It may be that man discovered that higher yields could be obtained under irrigation; far more likely that he discovered that the crop could be obtained more certainly and with less expenditure of energy when grown in water. Another possibility is that he realized that whereas the cultivation of dry-land paddy necessitated constant shifting of the area of cultivation, "wet" paddy could be grown continuously on the same land, thus facilitating the precautions necessary to protect the crop from wild animals.

In modern times the cultivation of dry-land paddy has been neglected by the cultivator, except in times of economic depression or of failure of the irrigated crop; and it has been frowned on by responsible governments owing to the danger of soil erosion as a result of "shifting" cultivation, with which dry-land paddy has been so closely connected. Dry-land paddy cultivation, however, need not be a shifting cultivation, and the dangers of soil erosion may be guarded against. The investigator has usually ignored the possibilities of dry-land paddy in favour of the already established irrigated system. In view of the desirability of increasing world production of rice and of the diminishing areas of suitable new irrigable land, the possibility of increasing the yield per acre of dry-land paddy merits attention, and a survey might be made of the land considered suitable for this form of cultivation.

It may be argued that vast areas of swamp land await development for wet paddy; it is possible, however, that the cost of reclamation may be found excessive, but that areas elsewhere may be suitable for development for dry paddy at a much lower cost.

Burkill[35] has rightly observed: "Though it is customary to speak of dry-land rices it must be remembered that they require a humid atmosphere and endure no desiccation. As a result of their demand for moisture, the area of the whole world in which dry-land cultivation is practised is limited. They demand an assured rainfall over three or four months, and this greatly limits their cultivation."

Under modern methods of cultivation, the most expensive item in wet-paddy cultivation is the irrigation water. One may visualize, however, the cultivation of dry paddy unrestricted by the vagaries of the weather on areas supplied with water under controlled irrigation. The amount of water required is much less than that for wet paddy, and irrigation would be required for a shorter period. The conservation of water for the cultivation of dry-land paddy would in many areas of low rainfall enable this crop to be grown profitably, whereas the water supply might prove to be inadequate or too costly for growing wet paddy.

PRIMITIVE METHODS OF CULTIVATION

In Burma, dry-land paddy is grown in the thickly wooded hills in regions having an annual rainfall of fifty inches or more. The area is felled and burnt in the dry season, and with the advent of rain is given a rough cultivation to work the ashes into the soil. On this the paddy is sown broadcast, either alone or with cotton. Little or no weeding is given to the growing crop. The paddy crop is harvested in September–October and the cotton picked from January to March. The area may produce a ratoon crop of cotton the following year, and is then abandoned to grow secondary jungle for a period of seven to ten years. The paddy crop is all consumed locally.[201]

A somewhat similar system obtains in the Philippines, where it is known as *Caingin*; and in Malaya under the name of *Padi huma*, commonly grown by the aborigine tribes, the Sakai. In Malaya, maize (*Zea Mays*) or Job's Tears (*Coix Lacryma-Jobi*) is frequently grown with the paddy. The paddy seed, either alone or with an admixture of maize or Job's Tears, is broadcasted, or more usually dibbled in by the simple process of scraping a depression with a stick, dropping the seed in the depression, and covering it with soil by the foot. The initial crop is usually heavy—if birds and rodents have been kept from it—while each succeeding crop, and usually two or three annual crops are taken, are necessarily lighter.

It must be emphasized that this simplest form of cultivation entails the wanton destruction of forest, all or practically all the trees being felled and burnt. Necessarily, responsible governments look with disfavour on this destruction and have endeavoured to suppress it, for apart from the wastage of timber, the abandoned clearings frequently fail to revert to forest, but become poor grassland, often after serious soil erosion by reason of the torrential rains experienced in the tropics.

Under good conditions in Malaya, that is, the use of virgin land and comparative freedom from pests, a yield of 1,500 to 2,000 lb. per acre of paddy can be obtained from the first crop, the two succeeding crops producing perhaps 1,200 and 800 lb. of paddy respectively.

The primitive methods described above should not be used for any future development of dry-land paddy cultivation.

JAPANESE METHODS

Dry-land paddy is well known in Japan where the annual area under this form of cultivation is about 350,000 acres, or 4·5 per cent of the total area planted with paddy in that country. It is grown in rotation—barley, paddy, wheat, soya beans—mainly in the Kanto district. Elsewhere it may be grown on the same land for two or three years, after which, on account of diminished yields, the fields are planted with other crops. Frequently the paddy is interplanted with wheat, barley or cotton. The seed is usually drilled, about $4\frac{1}{2}$ lb. per acre in rows about twenty-two inches apart, and the cotton fertilized with dung, ammonium sulphate, soya bean cake, superphosphate, and ashes. It is recommended that the fertilizers should supply about 80 lb. nitrogen, 67 lb. phosphoric acid, and 62 lb. potash per acre. After-cultivation consists mainly in cultivating and weeding two or three times, the plants being thinned to about four inches at the first cultivation, some of the seedlings removed being used to supply areas where the stand is unsatisfactory.

DRY PADDY IN KELANTAN

Both in the Philippines and in Malaya other systems of dry-land cultivation are recognized, some of which are of only local interest. The State of Kelantan, on the north-east of the Malay Peninsula, provides an example of dry-land paddy extensively planted, there being in this region about 45,000 acres under this system. The following account of a system known as *Padi Tugalan* is summarized from Craig's description.[55]

The dry-land paddy cultivation in Kelantan falls under two groups; that habitually planted with dry paddy, and that which can be used for either dry or irrigated paddy. The second group comprises but a small proportion, being in the lower-lying dry paddy-lands, the choice of wet or dry paddy depending, usually, on the inclination of the cultivator.

The soil throughout this dry-paddy area is markedly homogeneous, and though occasional ridges of slightly sandy soil are found, a heavy clay predominates. Only twelve distinct varieties are cultivated, and the maturation period varies from 173 to 197 days. The success or otherwise of dry paddy depends on a favourable monsoon. Kelantan suffers from a markedly dry season which may extend from the middle of February to the end of May, but which varies from year to year in duration and severity. During this dry season the land becomes so baked that the local plough is barely able to penetrate the soil and the small local cattle, which have to live on the sparse grazing provided by the baked paddy-fields are unable to drag the implement effectively. Ploughing commences at the end of June or early July when the land has been softened by rain, but has not dried out sufficiently to prevent puddling.

It is ploughed to a depth of about two inches, and in the subsequent dry weather is harrowed. The land is then allowed to lie for a period of ten days. Should rain fall after ploughing, harrowing becomes necessary. These operations are repeated twice more with appropriate intervals, in order to obtain a depth of cultivation of about three and a half inches and to kill weed growth. Finally, the land is ploughed and harrowed a fourth time and the seed planted in rough lines by dibbling. Subsequent cultivation is confined to weeding by cutting down the grass with a short knife at intervals. Throughout these proceedings the utmost care is taken to avoid puddling or packing the soil unduly.

For a successful crop the plants must be well established and twelve to eighteen inches high before the land becomes waterlogged. If the dry season has been severe and protracted the cultivation retards planting, until by the time the crop is ready for weeding, rain is of daily occurrence and weeding is ineffectual.

This system demands a large amount of labour and care which all cultivators are not prepared to give, and which greatly exceeds the labour required for wet-paddy cultivation.

Another dry-land system practised in north-east and east Malaya is known as *Padi Taburan*. In this system the land is ploughed and harrowed and the seed then broadcasted and harrowed in. No after-cultivation is done and the crop becomes choked by weeds.

Craig[56] truly remarks that the system is exceedingly wasteful, for not only is the crop small, but the land is fallowed for one or two seasons after the removal of two annual crops.

PHILIPPINE SYSTEMS

In the Philippines[51] two further dry-land systems are recognized, viz. upland or *secano* and *sabog* or broadcast. In the first-named system the land is ploughed and the seed either broadcast or sown in drills. While crops by this method do not compare favourably with wet-paddy cultivation, pure-line selection from good varieties has yielded surprisingly good results, the crop exceeding 115-fold.

Sabog cultivation is intermediate between upland and wet paddy. "The land is diked and graded and prepared as for transplanting, and the seed is then broadcast on the field. This practice is confined to a rather limited territory, and is used only for a second crop where the supply of water for irrigation is or may be inadequate. The crops obtained by this method are smaller than by transplanting. Its advantages are some saving of time, saving labour of transplanting, and the possibility of maturing a crop with less water than transplanted rice." Of the four varieties most favoured three are typical upland varieties but can thrive also as wet paddy. All mature in about 125 days. Seed is sown at the rate of 200 lb. per acre.

DRY-LAND PADDY IN JAMAICA

In Jamaica,[147] a fairly large amount of dry-land paddy was sown during the 1914–18 war. Planting took place at the beginning of the rainy season and the crop was reaped six months later. Yields of about 1,800 lb. of paddy per acre were recorded, with an average of about 1,000 to 1,400 lb. per acre. No account is given of the method of cultivation in Jamaica, from which it may be presumed that cultivation was reduced to a minimum. Hanson,[96] however, gives the following account of the method used by East Indian tenants on certain estates in Jamaica. A dry nursery was used. The land was ploughed and harrowed and the seedlings transplanted in furrows, three feet apart and six inches deep, "hills" of seedlings being spaced six inches apart in the furrows. The plants were moulded with a hoe when they started to grow. No record of yield is stated.

SOUTH AMERICA

The cultivation of dry-land paddy appears to have made headway in South America. Brazil is the largest producer of dry paddy in the

world, about 80 per cent of the total production in that country being obtained under this system, but without mechanization.

Venezuela has about 35,000 acres under paddy, most of which is dry-land. In many of the South American paddy areas, particularly in Colombia, climatic conditions make it possible to plant and crop at any time of the year. Given adequate water, therefore, the extension of dry-land paddy in South America should be possible.

CULTIVATION ELSEWHERE

A system of dry-land paddy cultivation was investigated[90] some years ago in Malaya. Under this system, four successive crops are grown followed by fallowing from four to six years, during which period the land reverts to grassland or secondary jungle, or a mixture of both, and the fields then become grazing ground for buffaloes. The land is low-lying and situated on the banks of a river, the fields being liable to occasional flooding. As a preliminary to cultivation the secondary jungle is cut down and all stumps and wood removed or burnt. The land is ploughed to a depth of two or three inches with a wooden plough. Should the field have been newly opened after a period of fallow, an interval of about a month is allowed to elapse between the first and second ploughing to give the land time to "weather," and to permit the grass thus turned in to rot. It is then cross-ploughed, and again ploughed in the same direction as the second ploughing. Finally, the land is harrowed once.

The seed paddy is steeped in water or in a weak solution of salt, only the seed that sinks being used for planting. While still wet, the seed is retained in a cool place for a day and a night, is then broadcasted at the rate of about 60 lb. per acre, and is covered by a single ploughing or by raking. Should weeds subsequently become numerous, the land may be weeded about six or eight weeks after planting, for which purpose a very short-handled hoe is used.

Yields by this method were in some cases 1,800 lb. per acre of paddy. The normal yields are below this figure, due largely to the use of inferior varieties of paddy. Under this system the land is not manured, so that crops rapidly diminish in yield with successive planting.

Considerable areas of dry-land paddy are grown in Indonesia,[157] though the area is decreasing. In 1940 the planted area was about 800,000 acres, or about 10 per cent of the total area under paddy.

Dry-land paddy has for long been grown in the tropical regions of Africa. Irvine[116] states that a considerable quantity is produced in northern Nigeria, where good crops are grown in quite open country

of the savannah-forest type with rainfall between thirty and fifty inches and where the undergrowth is naturally grass. Mention is made of considerable areas under these conditions in Togoland and also on steep stony slopes of the hills in that country, where it forms the main food of the people throughout the year. Mention is also made of its cultivation in the Gold Coast and in parts of Sierra Leone. The methods of cultivation do not greatly vary from those in Asia, and here again it is noted that the paddy is usually interplanted with other crops, corn, pumpkins, tomatoes, taro, and cassava being mentioned in this connection.

CONCLUSIONS

Evidence as to the possibility of extending the cultivation of dry-land paddy is inconclusive, but the indications are favourable for a thorough investigation as to the suitability of this form of cultivation. The bad systems of cultivation used in the past should not be allowed to prejudice the future of dry-land paddy cultivation. It must be remembered that paddy is a dry-land crop, and there seems no reason why it should not be cultivated in precisely the same way as other cereals, where climatic conditions allow.

There are a large number of varieties of dry-land paddy, and many other varieties that will grow under either dry or irrigated conditions. Hitherto research work on these varieties has been neglected in favour of selection and breeding of the wet-land types. Very considerable improvements have been effected as a result of this work, and there is no doubt that had the same degree of attention been given to the dry-land varieties the results would have placed this method of cultivation in a more favourable position than it at present occupies.

Chapter X

MECHANIZED CULTIVATION

Where Mechanization is Practised—Prerequisites of Mechanization—Mechanization Methods in the United States—Mechanization in British Guiana—Mechanized Cultivation in Australia—Mechanization Problems in Asia—Mechanization Experiments in Malaya—Mechanization with Market-garden Tractors—General Conclusions.

WHERE MECHANIZATION IS PRACTISED

An account of mechanized paddy cultivation must necessarily be largely a description of the methods of cultivation of the crop in the United States, where a sparse population was faced with the problem of developing vast areas of virgin land. It is evident that with the cheap and plentiful labour available in Asia, mechanization of paddy cultivation has hitherto been unnecessary. The economic conditions in Asia are, however, rapidly changing, calling for new and more up-to-date methods of cultivation of existing land and the more rapid development of new land to satisfy the ever-increasing demand for rice.

Other countries than the United States have adopted mechanized cultivation to some extent. In Spain[39] disc harrows especially adapted for the work are used, and a special harrow, known as a *rallôora*, is run through while the land is still moist. This implement consists of large discs a foot in diameter and set about a foot apart, which simply cut vertically into the soft soil. Following this, the field is ploughed with heavy inverting ploughs. The *rallôora* serves the double purpose of deeper aeration and of easing the work of the heavy plough. Mechanized methods are associated with paddy cultivation in Australia, and also in South America, but the problems presented in these countries are entirely different from those of Asia, where the demand is for implements that will carry out the initial clearing of virgin land of a boggy nature and the subsequent cultural operations on bog soils on which water control is imperfect.

In Italy, either disc or mouldboard ploughs, drawn by oxen,

horses, or tractors, are used for the preparation of the land. The bunds are usually made at time of ploughing, being made by the plough and finished off by hand. The land is then harrowed, and finally levelled with the *Speanone*, a long plank drawn by a horse. The seed may be drilled, or seedlings raised in a nursery are transplanted at about forty days, usually with the aid of a transplanter. There are now about sixteen different transplanters on the market, of which three are semi-automatic and the remainder fully automatic. The best of them are said to be fully satisfactory. Usually the growing crop is weeded three times, either by hand or by machine. Reaping is done by hand, but mechanical threshers of the ordinary type are used.[250]

PREREQUISITES OF MECHANIZATION

Successful mechanization of paddy cultivation demands an adequate supply of irrigable water, and a very highly efficient control of this water. Three other prerequisites in the United States are held to be: high temperatures, especially relatively high mean temperatures during the growing period; secondly, land that is comparatively level consisting of soil that will hold water, thus reducing loss of water by seepage; and thirdly, good surface drainage. It should be added that the area of land satisfying these conditions should be sufficiently extensive to justify large-scale operations.

Given these conditions, there is no reason why the methods so successfully adopted in the United States should not be applied with equal success to existing or new areas in Asia and elsewhere. Any attempt to mechanize paddy cultivation without first being assured of complete water control at all times is doomed to failure.

It is likely that the adoption of the American system in its entirety to Asiatic conditions would result in a diminution of yield per acre, due largely to the practice of broadcasting the seed instead of transplanting, and to less effective control over weeds.

MECHANIZATION METHODS IN THE UNITED STATES

Paddy had been grown in Louisiana for many years by primitive methods until about 1885, when farmers from the wheat-growing areas settled and adapted their methods of wheat culture to the cultivation of paddy. The success of their venture resulted in the development of the industry in other States where land was found to be equally suitable for the cultivation of paddy by similar methods. Thus, in the United States the cultivation of paddy follows closely that of other cereals. The methods differ in some respects in dif-

ferent States; the following account, however, indicates the practices that are general thoughout the country.*

Bunding. The contours are determined by a competent surveyor, and the various points on the contour line marked by a plough, the ploughed furrow indicating the base of the bund or levee. A tractor drawing ten or twelve ploughs then makes a round, back-furrowing to the furrow made by the team. In this way loose soil is drawn to the centre to provide material for building the bund. The choice of implement for making the bund depends on the bund to be made. Outside bunds which are to serve as one bank of the supply or drainage ditch are often built with a Fresno scraper, while the interior or field bunds are usually made with a home-made checker drawn by one or two tractors. Bunds on small fields may be built with a ditcher or V-crowder.

The checker is made of various sizes. The runners for the sides are usually made of 3-inch by 12-inch plank 16 to 24 feet long and are lined with steel. The front end is from 10 to 18 feet wide on the bottom, and the rear end is 3 to 6 feet wide on the bottom. The sides are 2 to 3 feet high and are set on a slant of $\frac{1}{4}$ to 1, the tops sloping outward. The checker is pulled with the wide end forward, the loose surface soil being drawn through the small end. This makes a bund of from twelve to twenty-four inches high and from four to six feet at the base. If the ground is rough or trashy, the checker may be weighted, so that it will push enough soil together to form a good bund. The checker is usually equipped with a device for raising and lowering the rear end, enabling the operator to lift it from bund to bund and to control the size of the bund. A checker can construct from ten to fifteen miles of bund a day. Newly constructed bunds must be made twice as high as required to allow for settling. The outside bunds are made higher than the field bunds and must be well constructed to avoid seepage and loss by overflowing.

Field bunds are made with gently sloping sides and high enough to hold a depth of about six inches of water. Farm machinery used for cultivating can pass readily over the bunds without damage to machinery or bund. The bunds are sown with paddy at the same time as the field and often produce a good crop. Well-constructed bunds with gently sloping sides therefore reduce all operational costs, and being planted with paddy there is less trouble with weeds.

Outside bunds and field bunds cannot be connected with a checker

* Largely drawn from the following publications of the U.S.A. Department of Agriculture: *Rice*, Misc. Pub. No. 615; *Rice Culture in the Southern States*, Farmers' Bul. No. 1808; *How to Grow Rice in the Sacramento Valley*, Farmers' Bul. No. 1240; together with information supplied by the U.S.A. Department of Agriculture by correspondence.

owing to the space needed for turning, and they are therefore connected by using the Fresno scraper or the tractor scraper. Preparation and repair of bunds is usually done in the winter months, so that they have time to settle before irrigation begins.

Preparation of the Land. In Louisiana and Texas the land is ploughed in the autumn and cultivated in the spring; in Arkansas and California ploughing, harrowing, and preparation for sowing are usually done just before seeding time in the spring. The aim appears to be to plough the land as soon after harvest as local circumstances permit and to leave the land in this condition for as long as possible to enable frost, rain, and sun to break down the land and to enable a good seed bed to be prepared with the minimum of cultivation. The choice between mouldboard and disc ploughs depends on the nature of the soil; the former are preferred for a hard and dry soil. The land is sometimes flooded before discing to break down clods and to fill holes. To prepare the seed bed, which should be slightly rough as a finely pulverized bed has a tendency to run together and remain cold and unfavourable for germination, the land is disc-harrowed and harrowed, the amount of harrowing depending on drainage and the condition of the soil. Heavy soils, when spring-ploughed, usually require more subsequent tillage to obtain a good seed bed than when ploughed in the winter, but light soils are prepared easily after either winter or spring ploughing. The final condition of the land when the paddy is to be broadcast should be such that there is no danger of seed being buried by breaking clods. The bed should, therefore, be fine unless the seed is to be broadcast in water, for in the latter case the water will break down the clods of earth. Winter ploughing is often followed by a light spring ploughing to kill all weeds before the paddy is planted.

Levelling.[221] The levelling of the land preparatory for irrigation is done with great care. The object is to remove the slightest differences in level which may have resulted from ploughing or cultivation, or which may exist naturally. On very uneven land the ordinary scraper pulled by a caterpillar tractor may be used. Subsequently a special scraper is used. It consists of a roughly half-cylindrical drum, one edge of which is in contact with the ground. This drum is fixed at the middle of a long frame some fifty feet long, supported at the four corners by wheels. When working, the lower side of the drum is level with the soil. Pulled by a tractor, the differences in level of the soil on which the wheels of the frame have to pass scarcely affect the horizontal on account of the length of the frame. When a bump is met, it is removed and the earth from this accumulated in the drum,

which thus pushes before it one or two cubic yards of earth. If the machine passes over a hollow it is automatically filled by earth contained in the drum.

The levelling is finished off with a sort of sledge called a "float." It consists of a frame $3\frac{1}{2}$ yards wide and from 7 to $9\frac{1}{2}$ yards long. The sides of the frame rest on the ground and supported across them is a scraper, while at back and front of the frame are two more scrapers.

Sowing. A feature of paddy cultivation in the United States, especially in California, is the sowing of the seed by aeroplane, by which method about 400 acres per day may be sown as compared with fifteen to forty acres by seeders or drills pulled by tractors, the cost of seeding by air being no more than by other methods.

The system of broadcasting the seed in water was first attempted in 1930 with the object of controlling weed growth. So successful did this prove to be that the system became generally accepted, until to-day about 90 per cent of the acreage under paddy in California is planted by this method. The operation is described[79] as follows: "A hopper that will hold about 600 lb. of seed rice or enough to sow five or six acres is built in the plane in front of and below the pilot's seat. The bottom of the hopper slants downward to an adjustable opening which runs the full width of the hopper. Through the opening the seed runs out on to a sloping baffleboard where it is caught by the draught from the airplane propeller and scattered over the field. The seed is sown quite evenly over the strip thirty to fifty feet wide for each trip of the plane across the field. To obtain uniform coverage and to prevent overlapping of the seeded area or missing some of the land, the pilot is guided by a flagman at each end of the field and by one in the middle if the field is large."

It should be noted that broadcasting, whether by aeroplane or other method, is almost invariably on land submerged to a depth of two or three inches. It is claimed that paddy sown on the water not only protects the seed from birds, but that it entails less labour in preparation of the seed bed because the water breaks down the clods. Furthermore, it reduces trouble from growth of early and mid-season types of water grass. Less seed is required when the paddy is sown in water than if sown on the surface of the soil, and the possibilities of getting good stands of paddy are better from seedlings in water than from seeding on the surface of the soil because less seed is covered with soil.

As an alternative to seeding by aeroplane, sowing with a grain drill or broadcasting with an end-gate seeder is practised. Broadcasting in water is usual on old paddy land, but on new land, or on land that is known to be free of water grass, the seed may be drilled

before the land is flooded. If broadcasted, the land should not be subsequently harrowed, for seed on land to be continuously submerged should never be covered with soil.

The broadcast sower consists of a small hopper under which are one or two horizontal discs fitted with ribs. A chain worked from the back axle makes the horizontal discs rotate at great speed, causing the paddy to be thrown over a width of about fifty feet. About 100 acres can be sown in a day.

The rate of seeding depends on a number of factors: the variety of paddy, quality of seed, fertility of the soil, condition of the seed bed, method of irrigation, date and method of planting, drainage, and upon whether the land is new or old. The seeding rate may thus vary from 90 to 160 lb. per acre. It is held that the rate of seeding should be sufficient "to produce stands that are thick enough to check weed growth and also to prevent excessive tillering, which might result in irregular ripening and reduced yields of inferior quality."[80] The effort to prevent or limit tillering will appear revolutionary to those accustomed to the transplanting method, but it appears to be one of the fundamental differences between the two systems.

The depth of seeding depends on the character of the soil, the condition of the seed bed, and on the drainage. Paddy can be sown deeper on a light warm soil than on a heavy cold one; on a poorly prepared seed bed the seed must be sown shallower than on a well-prepared one, while on land that cannot be adequately drained the seed should be lightly covered. Paddy will germinate through water, or through soil, but not through both.

Irrigation and Drainage. The subject of irrigation and drainage is treated in greater detail in another chapter; suffice here to record in outline the manipulation of water considered necessary under the American system of cultivation.

On heavy soils of California irrigation practice appears to vary somewhat to that employed elsewhere in the United States. In California the land is frequently irrigated and drained to germinate the seed. This is continued for about thirty days, when the land is irrigated once a week or ten days until the paddy is submerged. At the last irrigation preceding submergence, the water is drained off slowly. The land remains submerged for 90 to 140 days. Elsewhere in the United States, when the seedlings reach a height of about six to eight inches the land is submerged to a depth of one or two inches. As the plants grow, the depth of water is gradually increased until it is held at about five inches.

The fields must be drained and dried before harvest so that heavy machinery may be used. As a rule, heavy soils dry slowly, but their

42. Building a levee or bund with a checker, California

43. Contour ploughing with a tractor, India

44. A D.4 tractor towing a Mitchell seed-drill with the rear-gangs of a Martins disc-harrow hitched on behind as a covering harrow

45. The Endgate Broadcast-seeder

46. A—Paddy field being sown by an aeroplane which is seen approaching a flagman. B.—Seed rice dropping on the water from an aeroplane, U.S.A.

surface soon becomes baked and hard. Light soils should therefore be drained earlier than heavier soils because on such soils more time is required to form a crust on the surface which will support machinery. The water is usually held on the land until the paddy is fully headed and the heads are turned down and beginning to show the first signs of ripening. This is usually about two weeks before the crop is mature. If this drainage is too early the yield is reduced and some kernels are immature; if too long delayed there will be a loss of crop due to overripeness, resulting in shattering during harvest and possible loss of quality due to sun-cracking. No water should be allowed to enter the fields for about a week before final drainage. In this way, the water will be gradually lowered and lodging of the crop by rapid drainage obviated.

Harvesting. The crop is harvested with a combine or with the binder-thresher. With the combined harvester-thresher the paddy is cut with swathers and the swaths allowed to dry in the windrows for three or four days; a combine with a pick-up attachment is then used to thresh the paddy. When the combine-harvester is used, it is essential that driers be employed to reduce the moisture content of the grain to about 15 per cent, so that there is no deterioration during storage before milling. Harvesting by the combine-harvester has been more cautiously adopted in the southern States than in California owing to the difficulty in pulling the machines across bunds and low wet spots. The combine may either be self-propelled or pulled by a tractor. "Power for running the cutting and threshing units is supplied by a gasoline or a Diesel engine mounted on the frame of the combine. A self-propelled combine is also powered by a gasoline or a Diesel engine which supplies power both for propelling the machine and operating the threshing unit. Some combines are equipped with dual engines, one for propelling the combine and one for operating the cutting and threshing mechanism."[78] The self-propelled reaper thresher is becoming more and more general in paddy harvesting in the United States, just as is the drying of paddy before storage, which is a natural consequence of the reaper-binder.[221]

As an alternative to the combine-harvester, the crop is reaped by the binder-thresher method. The grain is cut with the usual grain binder and promptly shocked in such a manner that the grain is protected as far as possible from sun and rain. Careless shocking is said to result in rice of inferior quality. In the southern States a shock consists of about ten bundles and is capped with a bundle placed upright on the top with the heads downwards and in contact with the heads of the bundles in the shock. The straw of the capping

bundle is then pulled down and spread evenly so that it covers and protects the heads of the cap bundle and the underlying bundles. After about ten days in the shocks the grain is considered as cured and the milling quality of the paddy is thereby improved.

Official publications in the United States state that some of the binders are equipped with small auxiliary engines, so that they will continue to cut even though the bull wheel slides in wet or muddy ground. A binder drawn by a tractor and operated with a power take-off attachment is said to give much less trouble than the auxiliary engine. Power take-off binders are usually eight-foot or ten-foot cuts, whereas a six-foot binder was formerly the most common size. Most binders are drawn by tractors. Push binders, i.e. binders mounted on a frame and carried in front of a tractor, are sometimes used in opening up or cutting the first swath against the bunds. Small tractors, however, with power take-off attachments, if run on the bunds, can open up a field without much loss of paddy.

Threshing. Paddy harvested with the combine is threshed as it is cut. The paddy is carried by a conveyor-belt to the threshing part of the machine, which is similar to a stationary thresher. It consists essentially of a revolving cylinder and a concave with heavy metal teeth which strip the grain from the straw, shaker screens which separate the paddy from the straw, and aspirators or fans, which draw out or blow out the weed seeds, chaff, dirt, and other foreign matter. Threshing is best carried out when the grain is reasonably dry, otherwise there may be poor separation and loss of grain. Paddy from the combine-harvester always requires drying before storage, the moisture content therefore must be reduced to 14 per cent.

Rossin[221] has summed up the method of paddy cultivation in the United States by stating that as soon as threshed, the paddy is transported to a silo, there to be dried, stored, and milled. This, he states, is the characteristic of American paddy cultivation; the farm is reduced to its simplest form, while in California, in many cases, it is reduced to nothing. There, the farmer lives in the town and enters into contracts for labour, sowing, and other operations. He really only owns the land and possesses no equipment or buildings on his farm. In the States of the south-east, on the other hand, the farmer carries out cultivation personally. Nevertheless, the farm buildings are reduced to a residence and sometimes to rough shelters for the plant, with neither barns, cowsheds, nor, above all, storage sheds for the grain. As soon as the paddy is harvested it is taken from the farm, and the farmer's rôle is, strictly speaking, ended.

MECHANIZATION IN BRITISH GUIANA

A mechanized pilot scheme, known as the Mahaicony/Abary Scheme,[199] covering between 4,000 and 5,000 acres, was inaugurated in 1942 as a war-time production effort. On this area much useful work has been carried out in adapting agricultural machinery for the cultivation of paddy. From the experience gained it has been possible to devise a sequence of operations suitable for average field conditions in British Guiana.

The aim is to cultivate when the land is dry, and to drain off the water so that harvesting may be done on dry land. The straw left by the combine is burnt as soon as possible after harvest, as it is stated that straw has an adverse effect on the drying out of the fields. Ploughing-in stubble and straw is therefore not practised. Mould-board ploughs, it is stated, are unable to turn in stubble and loose straw, although disc ploughs prove successful in performing this work. The land is usually ploughed with a polydisc plough. Two- or three-disc harrowing usually breaks down the land sufficiently to obtain a satisfactory seed bed for the drilling or broadcasting of the seed.

A system of underwater cultivation has been adopted and is successful provided that there is a sufficient depth of water on the land, for it was found that tractors and harrows could travel through flooded fields and could effectively destroy vegetation. Track-laying tractors have proved unnecessary, wheeled tractors being successful in all operations.

Reaper-binders and threshers proved unsatisfactory; they were inefficient with a crop that tends to lodge, and the handling of the crop was also expensive, often inefficient, and usually resulted in much loss of grain on account of shattering. Windrowing was attempted, but was unsuccessful because the swather gave trouble and there was apt to be insufficient stubble on which to lay the windrow. Massey-Harris self-propelled combines with a cutting width of fourteen to nine feet, mounted on tracks, proved successful, as did the tractor-drawn Case combine with a six-foot cut. The former does excellent work in opening a field, and with a short standing crop; the latter proving more satisfactory in dealing with a lodged crop.

Harvesting in flooded fields has been possible; in fact, it is claimed that when the fields are too sticky and muddy for even the track-laying machines, the water lubricates the bulk-harvesting machine and keeps the tracks so free from mud that bogging down is unusual. Transport of paddy from field to dumps is effected with rubber-

tyred, steel-framed ox-carts, and from dumps to warehouse with rubber-tyred, tractor-drawn trailers.

Emphasis has already been made on the necessity of adequate water control for the successful mechanized cultivation of paddy. Under-water cultivation is no substitute for water control; in fact, to permit under-water cultivation water conditions have to be just right, not merely wet. To obtain these conditions, therefore, water control is essential. Furthermore, under-water cultivation is more expensive and depreciation of machinery greater than in dry-land cultivation. Under-water cultivation should therefore be looked upon as an expedient rather than a system.

The success of mechanized cultivation in British Guiana is largely due to the firm character of the underlying clay; this supports the machinery and prevents it from bogging down.

The success of the Mahaicony/Abary Scheme as a pilot scheme is undoubted, even though the scheme continues to operate at a loss, due in large measure to inadequate water control. Farmers throughout the colony have purchased mechanical equipment for the cultivation of their areas and for operating contract services. In no other tropical country has mechanized paddy production been so widely adopted as in British Guiana, where its influence is already reflected in the extended area under the crop, and larger units cultivated under one ownership.

MECHANIZED CULTIVATION IN AUSTRALIA

On the Murrumbidgee Irrigation Area in New South Wales, mechanized methods have been successfully practised for some years. The land is cultivated by plough, the seed sown at a shallow depth by an ordinary wheat drill, fertilizers applied with a drill, or subsequently broadcast after germination. The crop is harvested with a rice header of Australian manufacture. This is a side-cut auxiliary-driven tractor or horse-drawn header with eight- to twelve-feet cut, which cuts, threshes, winnows, and cleans the paddy in one operation. The machine is fitted with a large grain box and bagging platform so that the grain can be bagged as the header moves through the field.

Fore-cut automatic headers on crawler tractors are increasingly employed. They cut the headlands of a field without damage to the crop; for this reason many growers employ contractors with fore-cut auto headers to cut tracks around each bay. About eight miles of track are cut per 100 acres, costing about £8 per mile. Tractor units collect the bagged grain for transport to local mills or rail-head.[111] Mechanization in this area appears to present no prob-

lems, probably because the soil is a medium-heavy clay overlying a stiff clay subsoil, and to the fact that control of irrigation water is good.

MECHANIZATION PROBLEMS IN ASIA

The methods of mechanization so successfully applied in the United States, British Guiana, and Australia are not directly applicable to the conditions obtaining in most paddy-growing regions in Asia. The crux of the question is water control. In the other countries the rainfall is less and the seasons more defined than is usual in Asia. Furthermore, the heavy precipitations experienced make it very difficult to devise irrigation and drainage works that will effectively and quickly cope with the excess water. Cultivation, therefore, may have to be carried out on wet or flooded land.

A recent report[26] has pointed out that the smallholder is usually able to produce satisfactory crops under poor drainage conditions and with limited irrigation supplies, and it is not uncommon for him to carry on all production operations under flooded conditions due to improper drainage. Before mechanized machines can be operated successfully, however, drainage must be satisfactory, and the cost of improved drainage will be prohibitive unless the maximum efficiency of drainage systems is utilized. Maximum efficiency depends on carefully laid-out plans, taking full advantage of all natural drainage conditions. The above opinions were expressed with special reference to British Guiana, but they apply with equal force to the problem in Asia.

The condition of the land, however, is but one of the difficulties encountered in Asia; another is that of the very small divisions of the fields rendered necessary to ensure even distribution of water over an area which is not flat. The breaking down and subsequent reconstruction of the bunds is out of the question in such areas; the alternative must be the use of implements of great manœuvrability —a matter of extreme difficulty when cultivating heavy land with perhaps two or three inches of water lying on it. Mention must also be made of the present system of ownership of land usual in Asia; most of the land is worked in units of under five acres. Some of these difficulties are not applicable to all areas in the East. Many of the large regions of production are situated on practically flat land, thereby reducing the number of bunds necessary, while co-operative arrangements should not be impossible to overcome the problem arising from the multiplicity of owners. There remains the difficulty of cultivating soft boggy land and land that may be inundated at the time when cultivation becomes imperative.

MECHANIZATION EXPERIMENTS IN MALAYA

Until recently, little consideration has been given to the possibility of extending mechanization to the paddy-growing areas of Asia. Even now, investigations are on a small scale in most countries, but in Malaya considerable research into this problem has been undertaken in the past six years. Conditions under which the crop is grown in Malaya are typical of much of the paddy areas of Asia, so that any success in the present trials might find a wide application. While the work in Malaya has by no means reached finality, valuable experience has been gained which may soon be applied to the development of extensive new areas in that country.*

Condition of the Land. It has been pointed out that cultivation may have to be carried out in very wet land, in mud, or even in standing water. The experience to date points to the conclusion that the cultivation of wet peat land and of other land with no firm bottom is unlikely to be possible, the soil being too soft at the best of times so that special means must be devised for pulling implements. Thus it was found necessary in cultivating such areas to evolve tracks that make it possible to "float" the heavy track tractors so that they can pull implements without bogging down.

Ploughing can be carried out in areas with a firm bottom, but special wheels and implements are necessary to enable subsequent cultivation operations to be carried out in wet land. In this case, subsequent cultivation is apt to prove difficult due to the presence of surface water. The ideal would appear to be to establish the most rapid drainage system possible, so that dry cultivation can be effected.

Bog soils consisting of peat, and organic soils comprise much of the potential paddy-land in Malaya. Once the area has been cleared and all stumps removed, little difficulty is experienced in cultivating the land for paddy with tractors and other means of mechanized treatment. The success of the experimental work in Malaya with widely different types of soil are due to the many modifications of the standard machines effected to overcome the difficulty inseparable

* The Malayan investigations have been very fully reported in two "Special Mechanization Numbers" of the *Malayan Agricultural Journal*, Vol. 31, No. 1 (1948) and Vol. 32, No. 3 (1949), and in progress reports contained in other numbers of the *Journal*. The following account is largely drawn from these sources.

Since this book was written, a further Report[289] has been published on the investigations in Malaya, in which it is stated that the prospects for the mechanization of paddy cultivation on the peat soils are not promising, due almost entirely to the impossibility of clearing the land of hidden stumps and underground timbers.

from this type of cultivation, and in particular to the fitting of special wheels to prevent the machines from becoming bogged. Variations in soil type make it impossible to advocate the use of any particular type or system of cultivation. Furthermore, cultural methods may have to be changed from the traditional to make mechanization possible. One cannot do more, therefore, than indicate the broad lines of the exploratory work that has been done in Malaya.

Implements. Generally speaking, and rather surprisingly, the heavier types of tractors have proved more successful and more economical than the lighter types. Working in heavy land and under difficult cultural conditions it is obvious that high power is necessary. On wet paddy-land which has a hard bottom it has been found possible to use medium-sized tractors, such as the Fordson Major, on standard steel wheels. This type of machine was also satisfactory for use on dry paddy-land. Elsewhere, for use on wet areas, it was found that the standard wheels were unsuitable. The conclusion was reached that wheeled tractors are more suitable than track tractors (thus confirming experience in British Guiana), but "it has been shown that soil variation is such that certain wheel designs and certain tractor-implement combinations may be successful in some situations though quite useless in others."[99]

Regarding implements, Hartley[99] further points out, it has been found that although the integral power-lifting plough has not worked entirely satisfactorily owing to the difficulty in adjusting for depth, the advantages of the power-lifted implements are very great and it is therefore felt that attempts should be made to have all cultivations carried out by them so that the difficulty in negotiating headlands may be obviated. The cut-away disc-harrow has been most successful in peat areas, while in hard-pan areas mouldboard ploughs have been satisfactory.

Wheels. It was found essential to devise a type of wheel capable of supporting the tractor in soft land. While the standard wheels were satisfactory for dry land, in wet land and especially when the land had been ploughed or cultivated and the soil worked into a soft mud, it was evident that wheels must be devised that would prevent the machines from becoming bogged, or at best of preventing the wheels from absorbing most of the power. Extension rear wheels have been devised to solve this problem. In later types the extension wheel consists of a bolted-on ten-inch steel wheel, provided with large strakes consisting of steel plates ten inches long and six inches deep, set at an angle of 20° across the circumferential plane of the wheel. In a development of this, the solid extension wheels are enclosed. The front wheels are provided with a plain six-inch rim

bolted to the standard steel wheel. To overcome the liability of bogging in soft ground a larger roller is clamped on the front axle.

For final preparation of the land, when previous cultivations have rendered the soil so soft that the extension wheels tend to sink, paddle wheels were substituted for the rear wheels. The paddle wheels are thirty inches wide and fitted with strakes three and a half inches high. The solid extension wheels are retained for the front wheels, as paddle wheels in front make steering extremely difficult. For final cultivation, however, the use of paddles has been found useful in soft mud. Later advice is that front paddle wheels were never successful, and they have now been superseded by the single larger ten-inch roller.

After-cultivation. A series of implements are in use to work the land into a proper state for planting. The amount of cultivation and the type of implement used must, of course, depend on the type and condition of the soil.

Disc harrows have proved successful in wet land; care has to be taken, however, to set the discs so that the drag is not too great, as this may bog the tractor. A locally made toothed harrow, bogie mounted, for the Trusty tractor, has proved a useful implement for after-cultivation of wet paddy-land.

The "Kedah-type" roller, designed on the hand-operated wood roller traditionally used in many countries, has proved successful. It is constructed of steel, having a width of five feet, and an overall diameter of one foot, and weighs 475 lb. with two rolls or 323 lb. with the rear roll removed. This double roller has recently been largely superseded by a single ten-inch roller. The latter is said to be better in most cases than the drum roller. The drum roller was devised for deep and very wet land. It consists of two forty-five-gallon fuel drums mounted end to end on a long shaft and fitted longitudinally with wooden slats three inches high, the whole being mounted on a light steel frame and directly attached to the hydraulic power-lift. The weight can be varied by filling with water through the screw-on caps.

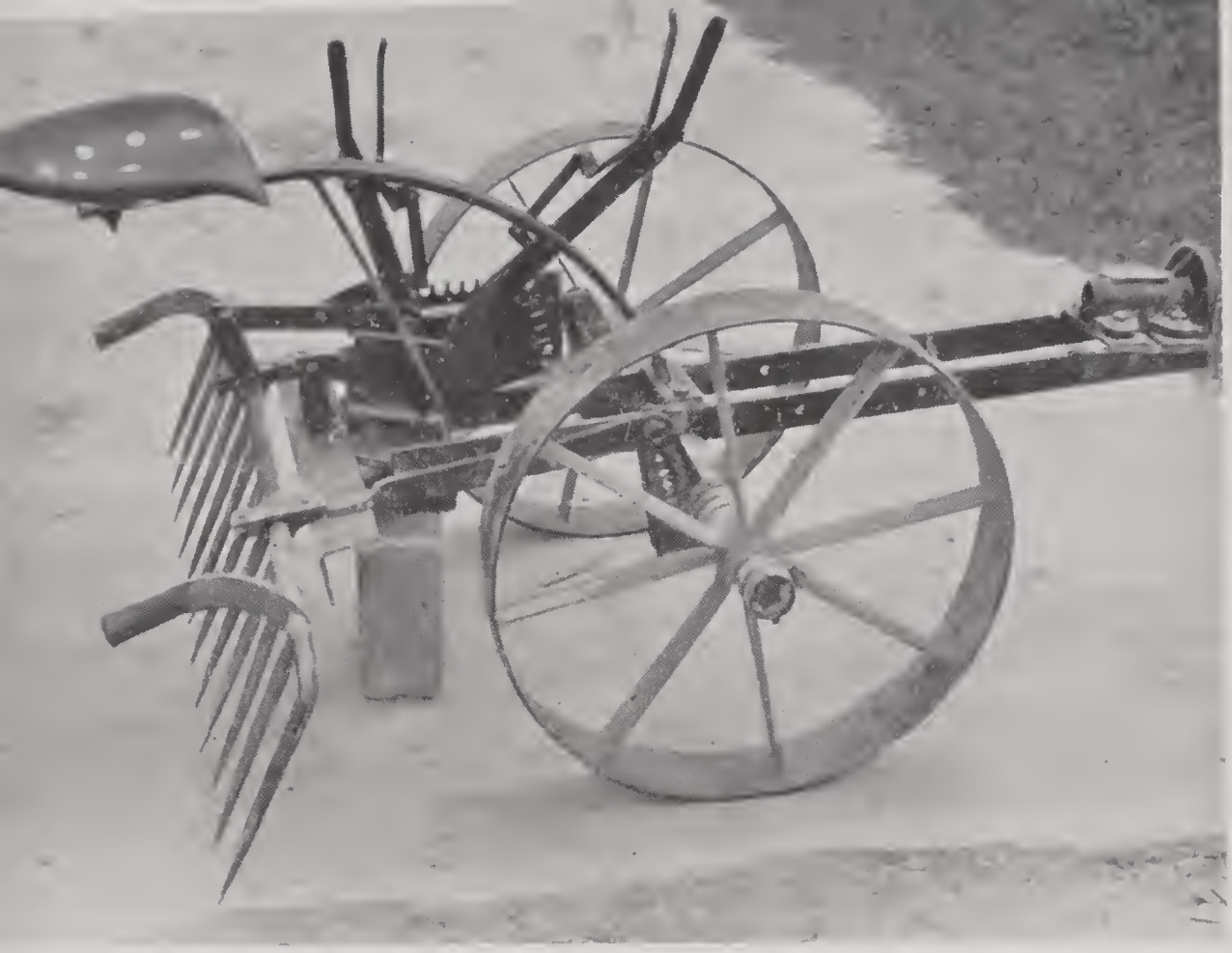
Rotary Cultivators. The Tillmore was modified by enclosing the wheels using light gauge sheet steel, to prevent clogging. Coleman[50] states: "This implement was first tried on paddy-land in a dry state and worked very well to a depth of three or four inches, but below that the tractor laboured badly and tended to stall. On 'sticky' land it proved useless as the draught was so great that the tractor had insufficient power to overcome rolling resistance and operate the power take-off, and the rotary screw clogged up. In wet conditions,

47. Self-propelled combine harvesting paddy, U.S.A.

48. Under-water cultivation, British Guiana

49. Extension wheel fitted to tractor, Malaya

50. D.4 "Drum" type roller, Malaya



51. A toothed harrow, bogey mounted, for the Trusty tractor, Malaya

52. Double "Kedah" type roller, Malaya

53. The Howard Rotovator Gem pumping water from paddy field in preparation for cultivation, Thailand

54. The Howard Rotoho Gem, British Guiana

however, the machine worked well, and was self-cleaning as it worked. The depth of work was four inches. . . ."

Drilling. Under very variable conditions little difficulty is experienced in drilling the seed. For the cultivation of dry-land paddy the opinion is expressed that the local method of dibbling facilitates inter-cultivation and weeding. On wet paddy-land, however, the depth is apt to vary and the seed rate to be too high. Furthermore, if heavy rain falls soon after drilling and patches of ground become waterlogged, germination is uneven, as the seed will not germinate in the waterlogged areas. It is suggested that more satisfactory results would follow from allowing the seed to germinate by rainfall only, subsequently flooding the land when the seedlings are established.

Harvesters. Mechanical harvesting has so far proved to be unsatisfactory in Malaya. Various modifications have been made to the machines in an attempt to overcome local difficulties such as negotiating soft patches. Subsequent drying in stooks was unsatisfactory; when the paddy was threshed it was found that sun-cracking in the stooks had been severe, in addition to which much grain was lost by shattering. It is evident that further investigations on this aspect of mechanization are necessary.

MECHANICAL CULTIVATION WITH MARKET-GARDEN TRACTORS

One would expect that the light market-garden tractor would prove ideal for the cultivation of paddy on the small individual areas usual in Asia by reason of its convenient size, ease of manoeuvre, and comparatively low initial cost. In Thailand,[282] the Howard Rotavator Gem provided with a power take-off pulley has been used to pump the water from each small division of the field in turn, the area from which the water has been pumped being allowed to dry out for a short period, and then cultivated with the same Rotavator. The machine is provided with extra large wheels which penetrate the mud and find the bottom, a system which has been found preferable to the fitting of wheels which make the machine "float" on the mud.

Tests of several makes of market-garden tractors have been made in Malaya.[12] It is convenient to consider separately the performances of these machines for dry-paddy cultivation and for wet cultivation.

Dry-paddy Cultivation. Four makes of tractor were compared in a test carried out in the state of Kelantan.[12] In view of the fact that the operators were inexperienced in the use of these machines, it is unwise to compare the performances of one make against another. The average man-hours per acre for cultivation, planting, weeding,

and supplying were approximately the same as when using the native plough and harrow. The rotary hoe, however, was superior in this respect, but this advantage was largely lost by the time the second weeding was performed.

Wet-paddy Cultivation. All machines performed reasonably well in the initial ploughing or cultivation in a moist soil. Subsequent disc harrowing in sticky ground proved very difficult. A second ploughing was possible but most exhausting to the operator. Second harrowing on flooded land proved impossible, discs could not be used as they penetrated into the mud and built up a wall of mud in front. A locally constructed tined harrow attached worked well, but a Cambridge roll used after ploughing clogged up and sank into the mud. The conclusion was reached[12] that in their present form none of the machines and their standard equipment are well suited to wet-paddy cultivation. All were comparatively expensive to run and most of them required a disproportionate amount of manual labour to operate. Ashby concludes with the opinion that "small engines operating under difficult conditions are more prone to stoppages from minor mechanical faults than are larger ones, nor do they require less frequent or less skilled servicing. There are many grounds for thinking that the small horticultural type of tractor, of which some are capable of good and efficient work on dry land, is not likely to be of much value to the smallholder for wet cultivation."

One is reluctant to preclude the use of small cultivators for wet-paddy cultivation, and finality can hardly yet have been reached in judgement on the performance of these machines. They have recently been introduced into British Guiana where the writer saw a 6 h.p. "Roteho Gem" rotary hoe working on land with about four inches of standing water; under these conditions it was easy to operate and appeared to do good work. Its performance was said to be about one acre a day, and its consumption about four gallons of gasoline per acre. It is evident, however, that such small machines have not been thoroughly tested, and with many of them efficiency of operation and the rate of work must be considerably improved if they are to be of service for wet cultivation.

GENERAL CONCLUSIONS

Experimental work on the use of mechanized cultivation of paddy-land in Asia has by no means reached a final stage. It is evident that the cultivation of the crop with the aid of tractors is possible, although further modifications of the implements, as well as of the

tractors, may be necessary. Authorities on the spot are of the opinion that it is in the development of new large areas that mechanical cultivation is likely to prove of most value. They are less optimistic regarding the existing areas under numerous small ownerships, suggesting that if increased crops are shown to be possible as a result of mechanized cultivation, a change from the present system might appeal to the cultivator. This would appear to be too conservative a view. There is no reason to doubt that mechanization would be adopted by the cultivators in Asia as it has in British Guiana if they are shown that it will work, and provided that the cultivators' ownership of land is retained, and the cost is within his means. Mechanization of dry-land cultivation appears to hold more immediate promise of success. It would appear that the Malayan experiments are conducted on land over which there is not complete water control. One must regard water control as of first importance; mechanization without it is doomed to failure.

The experimental work in Malaya on harvesting has given disappointing results, due mainly, it would seem, to the fact that the land is not in a suitable condition to carry the equipment. The solution of the problem is not to adapt present machinery to the wet conditions on which it is expected to work, but to obtain better water control, so that the land can be dry at harvest time. It would appear, too, that the stooking of paddy in countries of uncertain weather conditions will result in much of the grain being damaged or lost, and this suggests that artificial drying is essential in connection with mechanical methods of harvesting.

Certain cane-sugar estates in British Guiana use cultivating equipment pulled by cable operated from two barges on irrigation canals. Mechanized cultivation of land which will not support heavy machinery is possible by this method. There appears to be no evidence that this system has been contemplated in connection with paddy cultivation.

Chapter XI

PLANT FOOD REQUIREMENTS OF PADDY

Nitrogen—Nitrogen Fixation in Paddy Soils—Response to Nitrogenous Fertilizers—Phosphorus—Potassium—Calcium —Balance of Fertilizer Elements in the Soil—Trace Elements.

NITROGEN

THE three most important plant food requirements of paddy are nitrogen, phosphorus, and potassium. Calcium and certain other elements may also exercise a great influence on the growth of the plant, although the quantities required are small.

The crop receives part of its fertilizer requirement in solution in the irrigation water. Investigations in Indonesia[83] have shown that this applies especially to potash, although phosphates may also be supplied in appreciable quantities. Den Berger[286] in Java concluded that all the nutritive elements, with the exception of nitrogen and phosphorus, are supplied by the water in sufficient quantity to replenish the losses of these elements absorbed by the plants. This applies to irrigation water obtained from rivers; the nutritive elements obtained from water from lakes, wells, and artificial reservoirs are less.

The paddy plant depends mainly for its nitrogen upon the decomposition of organic matter under anaerobic conditions, and in the earlier stages of growth takes up its nitrogen in the form of ammonia and not as nitrates.[133] Many experiments could be quoted to prove that the application of nitrogen in the form of nitrates in the earlier stages of growth is without effect or is even deleterious to the plant. This may be because nitrates are easily leached and in solution are lost to the plant, while the deleterious effect may be due to the conversion of nitrates to nitrites. In the later stages of growth manuring with nitrates has sometimes proved to be advantageous. This lack of favourable response to sodium nitrate is not thought to be due to its effect on the physical condition of the soil.[154] The utilization by paddy of ammonia and nitric nitrogen is affected by the reaction of the medium, but plants supplied with ammonia make better growth at all reactions than those supplied with nitrate.[234]

Bamji[18] found that there is no increase in inorganic nitrogen under field conditions with the addition of fertilizers. The ammoniacal nitrogen is higher than the nitrate nitrogen and while no relationship exists between nitrate nitrogen and organic nitrogen, the ratio between ammoniacal nitrogen and organic nitrogen is more or less constant.

NITROGEN FIXATION IN PADDY SOILS

Most authorities are agreed that paddy soils have the power to fix nitrogen but are not agreed as to how this takes place. Azotobacter are always found in large numbers in paddy soils, and these in association with algae in the presence of growing paddy roots may bring about the fixation. Uppal,[263] writing of the soils of Karjat, India, observes that azotobacter has an important rôle in the nitrogen recuperation of paddy soils. The species is stimulated when associated with the growing roots of paddy, which seem to increase the efficacy of bacterial nitrogen fixation. He further states that there is a marked periodicity in the number of bacteria, and during the monsoon there is an increase in the nitrogen content of paddy soils. Fallow soils do not support a larger population of azotobacter. Dey[63] agrees that algae are the main agents of nitrogen fixation in paddy-fields, but denies the importance of bacteria. Writing at a later date, Sulaiman[245] remarks that the abundant growth of algae is common in submerged paddy-fields, but the dead algae do not provide a source of energy for azotobacter. He suggests that the algal growth in the fields do not assist growth of or nitrogen fixation by azotobacter. Dhar[68] had previously asserted that nitrogen fixation can take place in the complete absence of bacteria provided energy is available from the photochemical or induced oxidation of sugars.

Dey[65] proved that a considerable amount of nitrogen is fixed in alkaline soils when they remain submerged and exposed to sunlight, the addition of calcium carbonate to acid soils stimulating both algal growth and nitrogen fixation. Four species of blue-green algae, three *Anabaenas*, and one *Phoridium* were shown to be responsible for this nitrogen fixation. Investigators in India have also isolated a more acid-tolerant azotobacter (*Az. indicum*) capable of fixing nitrogen, while preliminary results are quoted by Sethi[232] showing that there are one or more nitrogen-fixing bacteria within the tissue of the leaves.

Harrison and Aiyer[98] have sought to explain how nitrogen fixation takes place, and how the roots of the paddy plant—a dry-land root and not an aquatic—are provided with the necessary oxygen. They showed that the chief gases produced during the fermentation are

methane, hydrogen, carbon dioxide, and nitrogen. These, on rising to the surface, encounter active aerobic bacteria which oxidize methane to carbon dioxide, and the hydrogen to water. The carbon dioxide is then taken up by the green algae present on the surface and the oxygen is liberated. Thus the undesirable gases are removed and only oxygen and nitrogen are evolved for the root system. Evidence has also been adduced to show that plant roots assist in facilitating oxidation changes in the soil.

Many writers have endeavoured to discover the condition of nitrogen in the soil and its relationship with the paddy plant. Bhuigan[29] showed that the total nitrogen in the soil remains practically constant throughout the year. He found that the ammonia content remained at a considerably higher level soon after waterlogging; it then decreased and remained at a low level. Nitrate was absent during the waterlogging period, but may accumulate after harvest. Hydrolysable nitrogen fluctuated irregularly. Soluble nitrogen was at its maximum in July and August. The results on the whole show that the two different conditions that exist in a paddy-field have little influence on the organic make-up of the soil. Barrera[21] determined the nitrogen content of the soil during the four stages in the growth of irrigated paddy. Generally he found that the nitrogen content during the last sampling was greater than that obtained when the soil was flooded and before the application of fertilizer. Aoki[8] showed that the reduction of nitrate attained a maximum on the seventh day after the soil had become waterlogged. The reduction of nitrate increased with increase of temperature to 35° C. and with the lowering of the soil potential.

Sethi[232] summarizing the investigations on manuring of paddy in India, states that where fermentation takes place under swampy conditions of an anaerobic nature, instead of nitric acid, ammonia is produced, which is readily assimilated by the paddy plant. The nitrates, on decomposition under this condition, liberate the nitrogen in a free state, in which it is of no use to the plant. Loss of ammonia will be slight for although it is soluble in water, the soil has such a great attraction for ammonia that it removes it from the solution and prevents its loss by leaching. Thus ammonium compounds or substances which yield ammonia under anaerobic conditions are more useful as manures than are nitrates.

RESPONSE TO NITROGENOUS FERTILIZERS

The effect on the plant of increasing the amount of nitrogen in the soil by the application of fertilizers has been studied in many

countries. While field experiments have shown that there is no definite correlation between crop productivity and the C:N ratio of the soil,[118] and no significant correlation between soil nitrogen and the nitrogen percentage in the grain,[266] yet ammoniacal fertilizers alone and in combination with other artificials will result in an increase in the whole grain weight, mainly in the endosperm and not in the husk and bran.[254] Sorono[240] found that the leaves of plants fertilized with ammonium sulphate contained more chlorophyll and less ash than those receiving sodium nitrate, and by increasing the ratio of nitrogen application the water content of the leaves was increased and the ash decreased. Libatiqui[141] found that the application of ammonium sulphate in moderate quantities tended to develop and in large quantities to retard root development of paddy. On the other hand, lack of nitrogen is considered[131] to be responsible for most of the abnormal growth and low yields.

In the first stages of growth, inorganic fertilizers, e.g. quick manures, are more effective in producing growth than organic manures, but the latter produce healthier plants.[132] Ammonium sulphate, or fertilizers that supply the nitrogen in the form of ammonia, is the most effective for paddy in its early stages, although Dennett[67] found that insoluble nitrogen was more effective than ammonium sulphate. There is, however, a considerable weight of evidence that the continued use of ammonium sulphate over a number of years causes deterioration of fertility and a decline in yields, after the first few years of application when yields are considerably increased by its use. Chang[43] has remarked on this decline, while Rhind and Tin,[216] growing paddy continuously on the same land for ten years, found that 100 lb. per acre per annum of ammonium sulphate gave yields always significantly higher than those not treated, but that after the first three years the increase in yield declined from a maximum of 1,062 lb. per acre to a minimum of 321 lb. per acre. These observations suggest that the balance between the nitrogen and other fertilizing elements required adjustment. Anderson[7] has observed that provided other nutrients are not the limiting factor yields are substantially increased by the addition of a nitrogen fertilizer. He compares the efficacy of urea and ammonium nitrate with ammonium sulphate, and concludes that ammonium sulphate is usually the most efficient nitrogen fertilizer, but that urea is often preferable to ammonium sulphate. Tokuoka[260] is of opinion that urea-gypsum is equal or superior to ammonium sulphate.

Investigators in India, as a result of a long series of experiments, have come to the conclusion that paddy in all circumstances responds

to the application of nitrogen. Sethi[232] states that it is difficult to find an instance where the application of nitrogen failed to show a response, while Gushchin[93] states that nitrogen is found to be the most necessary fertilizer in the Soviet Union.

In many regions it has been found that while the young paddy plant responds to ammoniacal nitrogen and not to nitrate nitrogen, in the later stages of growth nitrate nitrogen is effective. Investigations in India,[232] summarized by Sethi, showed that from a solution of ammonium sulphate the plant in all stages of growth absorbed a greater quantity of ammonium ions than of sulphate ions. "The absorption of ammonium ions decreased as the plant aged. The absorption of ammonium ion is independent of the presence or absence of nitrate ion or any other ion, as the same quantity of ammonium ions was absorbed from all solutions at a particular stage of growth. It was considered possible that the absorption of ammoniacal nitrogen in the early stages of growth of the rice plant and of nitrate ions in the later stages might be correlated to the iso-electric point of the proteins of the protoplasm of the tissues of the rice plant. The changes in the pH value of the soil, of rice plants treated respectively with ammonium sulphate, sodium nitrate, and a mixture of the two salts on an equal nitrogen basis, and of untreated rice plants were therefore determined. The pH value of the soil manured with sodium nitrate was always the highest, of the soil manured with ammonium sulphate lowest, while that of the soil manured with a mixture, midway between the two. It was found that the iso-electric point of the plant tissue lay between pH 4·1 and pH 4·4. At this hydrogen-ion concentration the proteins of the protoplasm will neither behave as acids nor bases, as the electric discharge on the proteins is neutral. The preferential absorption of ammoniacal ions in the earlier stages was thus found to be due to the electric charge on the proteins of the cells."

PHOSPHORUS

Apart from phosphates brought in solution in irrigation water, there is no natural means of increase of this element in the field, and as the plant removes considerable quantities from the soil, it may be anticipated that the crop will respond to applications of phosphate. Manuring with phosphates frequently gives increased yields, but in many cases it has failed to show any response. Phosphates tend to increase the yield of grain but not of straw,[43] while from Greece it is reported[169] that in a loamy soil deficient in phosphate and rich in nitrogen and potash the addition of phosphate not only increased yield but caused the crop to ripen earlier.

In sand cultures, Sircar and Sen[237] found that progressive phosphate deficiency led to progressive reduction in height and tillering. The intake of nitrogen was found to depend on the phosphorus concentration, and they concluded that phosphorus is not only useful in the early stages of growth, but may be utilized in the later stages of development. Phosphates and potash increase the growth of roots relative to tops, whereas nitrogen increases the growth of tops.[229] In Malaya it was found that the addition of phosphates had a more marked effect on light soils than on heavy soils, while from Japan it is reported[207] that larger quantities of phosphate are used on soils derived from volcanic ash than on sandy or alluvial soils. In Japan the amount of phosphoric acid applied is greater in the cold regions than in the warm regions.

POTASSIUM

Potash is less generally required on paddy soils, probably because such soils are usually of a heavy nature and contain adequate quantities of this element. Chang[43] found that potash did not affect yields. Similar results are general, but on light soils potash frequently gives an increased yield. In Japan[207] the yield of irrigated paddy is not materially increased by applications of potash above 20 lb. per acre. While potash is generally ineffective in increasing yields, when used in conjunction with the application of nitrogen and phosphorus it not infrequently produces higher crops. On the upland areas of the Philippines, potash is found to be the soil base absorbed in greatest amount. The conclusions of Koyanagi[137] concerning the use of potash in Japan were that without potash plants had a higher percentage of sugar and a lower percentage of starch than those receiving potash. He concluded that excess potash is to be avoided, but that small additions of this element to the soil are beneficial.

CALCIUM

Paddy appears to flourish best in a slightly acid soil. It might reasonably be expected therefore that additions of calcium to the soil would be without effect on yield. While in most cases this is true, on some very heavy soils the application of calcium may exert a beneficial effect on the soil texture, and may also stimulate nitrogen fixation. In some parts of India[232] the addition of calcium is only useful in large quantities and this is found to be uneconomic.

BALANCE OF FERTILIZER ELEMENTS IN THE SOIL

The application of a single element to the soil is usually found to be beneficial only within fairly narrow limits. This is but to be

expected, for such single addition if applied in quantity must upset the balance of fertilizer materials in the soil. The amount of any one element which the plant can absorb depends on this balance. Shibuya and Saeki[233A], for instance, showed that the uptake of ammonia nitrogen by paddy causes greater absorption of phosphoric acid than does the uptake of nitrate nitrogen, which contributes to greater absorption of potash; and Okada[174] states that the application of phosphorus increases the absorption of nitrogen by paddy and hastens maturity. On the light sandy and clay-loam soils in the Central Provinces of India, Dave[62] found that high and profitable yields were only obtained with phosphorus and nitrogen fertilizers, the most effective $N : P_2O_5$ ratio being 1 : 1. Ichikawa[113] in Japan concluded that a deficiency of phosphorus and nitrogen decreased yield, silica and nitrogen content increased it, while those of phosphorus and calcium decreased the yield. The general experience concerning the application of fertilizers on paddy land has resulted in the accumulation of considerable experience on the manuring of the crop with mixtures containing varying amounts of nitrogen, phosphorus, and potash, but with very little exact knowledge on the nutritional requirements of paddy. Necessarily, the most suitable proportions of the elements to apply will vary according to the nature of the soil, especially in view of the fact that in some instances no increase in yield results from the application of fertilizers. But to give a few typical instances one may quote the following: In Madras, the most remunerative application is stated to be 30 lb. nitrogen and 20 lb. phosphoric acid. In the Central Provinces of India 20 lb. nitrogen and 20 lb. phosphoric acid have been recommended.[62] In Japan[207] the optimum applications appear to range from about 50 to 90 lb. nitrogen, 35 to 70 lb. phosphoric acid, and 18 to 50 lb. of potash. In Thailand departmental recommendations are stated to be 44 lb. phosphoric acid and 22 lb. nitrogen, while in Indo-China the standard recommendation is 9 to 18 lb. nitrogen and 36 lb. phosphoric acid. In Bulgaria[140] 58 lb. phosphoric acid, 30 lb. nitrogen, and 30 lb. potash is recommended.

TRACE ELEMENTS

Knowledge of trace elements in relation to paddy growth is incomplete, but there is reason to believe that they play an important rôle in all stages of the development of the plant. It is possible that the limiting factor of growth and yield is frequently to be found in the deficiency or excess of an element or elements in the soil other than nitrogen, phosphorus, and potassium, although the plant requirements of such element or elements may be very small.

Iron and manganese are undoubtedly the two most important of these trace elements. An average crop removes about 1 lb. of iron from the soil and a similar quantity of manganese. Iron deficiency results in chlorosis and most commonly occurs in calcareous soils. Usually farmyard manure will serve to counteract any such deficiency, and spraying with ferrous sulphate is also effective. In parts of Japan,[208] particularly on sandy soil, the iron content in paddy-fields has been so depleted that a condition of "iron-podzolization" has resulted. Paddy grown on such soil is particularly susceptible to brown spot disease, which it is found may be substantially reduced if "iron-rich" soil, up to about fifty tons per acre, from Red Podzolic soils is added. The addition of this red silty clay also results in the improvement in the growth of the paddy. The beneficial factor is believed to be iron, but some investigations indicate that manganese and soluble silica are of importance in reducing brown spot disease and in the improvement of growth and yield.

When Red Podzolic soil is not available, the addition of iron filings is recommended by the Japanese authorities, while in some districts mud balls, made of iron-rich subsoil and ammonium sulphate, are placed between the rows of paddy plants.

Deficiency of manganese may occur in neutral calcareous or very sandy soils, but is not common. Excess of manganese, however, is quite common and may exert a toxic effect through suppression of iron availability. Paddy in flooded soil[242] will tolerate large quantities of soluble iron and manganese if the soil is supplied with actively decomposing matter.

It would appear probable that the absorption of iron and manganese by the paddy plant is related to the uptake of sulphur. Sulphur deficiency results in chlorosis, stunting, diminution of leaf area and tillering, and failure to reach maturity. The deficiency may be corrected by the application of 10 lb. per acre of sulphur as elemental, or as pyrites, gypsum, manganese sulphate or other sulphate, nitrogenous or phosphatic fertilizers containing sulphur, but farmyard manure will not supply the necessary sulphur.[3]

Symptoms of boron, copper, and zinc deficiency have been obtained in cultural solutions, but field evidence is incomplete. Tokuoka and Mooruka[261] showed that a small amount of boron added to the soil increased germination and yield, but had no effect on the straw and roots. In cultural solutions, boron in excess of 2 p.p.m. is toxic. Tokuoka[259] also states that traces of boron were almost without influence on growth dry weight, though within defined limits it may increase yield of grain, or accelerate leaf growth, while reducing nitrogen uptake.

A minute trace of zinc is said to speed up growth of the plant and to increase grain yield, but in cultural solution it is toxic beyond 1 p.p.m. It is suggested that up to this limit zinc favourably affects nitrogen intake, the C/N ratio of the plant being proportional to the amount of zinc added.

Minute traces of copper have a favourable effect on growth, maturation, and yield, but larger amounts are toxic. There is evidence that progressive traces of copper increase the amount of nitrogen in the stem and root. The copper content of the paddy plant shows regular fluctuations in the course of development, absorption being at the maximum during the period of rapid growth and at the time of seed production.[228]

In water cultures, the addition of silicon to the solution proves beneficial, effects which are more marked the greater the amount of nitrogen given. Increase of grain and straw due to added silica decrease with the increasing doses of phosphorus. Grains of silica-deficient plants have numerous brown spots.[117] Resistance to blast disease is stated to increase with the silica supply and to decrease with the amount of fertilizer given when the soil moisture is sufficient.[246]

In pot cultures, increases of yield beyond those derived from ammonium sulphate alone were obtained by the addition of manganese, zinc, and copper, singly or in combination. Japanese work has also shown the stimulating effect of sodium fluoride on the growth of paddy, but quantities over 1 lb. per acre were toxic.

Pot experiments with vanadium additions showed that this element stimulated tiller development and increased yield of straw and grain, though at first the growth of straw was retarded. Vanadium may have some stimulating effect on azotobacter.

It would appear that maximum yield depends on a proper ratio of lime to magnesium, and it is suggested that the ratio should be 1 : 1.[13] The appearance of "white tip" is associated with the lack of balance between these two elements in the soil. Marlin,[151] who also associates "white tip" with magnesium deficiency and lack of balance between calcium and magnesium, states that the preferred ratio is 1 : 3. Recent investigations, however, by Cralley[58] indicate that the disease is caused by a nematode; symptoms are similar to those caused by *Aphelenchoides oryzae* Yokoo, found in Japan.

The above evidence concerning the importance of trace elements on paddy growth is sufficient to show that there are a number of elements whose presence is essential in available form to enable the plant to absorb nitrogen, phosphates, and potash, and these trace elements may profoundly affect the growth and development of the

plant at all stages. Undoubtedly, large quantities of most of these trace elements are extremely toxic, and until their functions are better understood the practical application of much of this investigation must be postponed. It appears possible, however, that in many cases the absence or insufficiency of certain of these trace elements in the soil, or lack of balance between them and the nitrogen, phosphorus, and potash, may account for the fact that in certain areas of low yield the application of the usual fertilizers is followed by no significant increase of crop. Furthermore, the resistance of the plant to certain diseases has been noted by several authorities; it may well be that increase in knowledge of the ideal balance of certain trace elements in the soil may lead to developments in methods of disease control.

Chapter XII

FERTILIZERS AND MANURES

Areas without Manures—Fertilizing the Nursery—Results of Experiments—Fertilizer Practices—Time of Application of Fertilizer—Fertilizer Requirements of Asia—Organic Manures—Green Manures—Fertilizers with Organic Matter—Oxidation-reduction Zones in Waterlogged Soils—Conclusions.

AREAS WITHOUT MANURES

THE manuring of paddy is such a complicated problem and the evidence as to its efficacy is so conflicting that it is unwise to be too dogmatic on the subject. Comparison with other cereals provides no guide to the manurial requirements of the crop, for whereas other cereals are grown on dry land, paddy is grown in water. Vast areas under paddy have been cultivated annually in Asia for centuries without manuring, yet the yield remains at a remunerative level.

It has been argued that the constant yields obtained under these conditions are invariably low, and that when fertilizers are employed, as in Japan, China, and Europe, yields are high. It is probable, however, that these high yields are due in great measure to latitude, longer days of sunshine, and the effect of frost on the soil during the winter months. It might reasonably be expected that if the unmanured paddy-lands of Asia were so deficient in plant food as to produce minimum crops, the application of almost any fertilizer would produce an immediate and great response, but this is by no means always the case.

Artificial manures have been applied with success in many countries, but in the East, although significantly increased yields have been recorded in numerous experiments, their use is by no means widespread, due perhaps to the widely divergent results obtained, but also in no small measure to the poverty of cultivators which precludes them from purchasing such manures. Ignatieff[114] has deplored the fact that in some countries experiments with fertilizers have been postponed on the ground that their use would not be profitable to the cultivator. This, he points out, is unfortunate,

because it takes many years of experimentation to develop sound recommendations for fertilizers. Further, technical advances have been made in the manufacture of fertilizers, and it may well be that, with further advances, prices of these materials may come within the reach of cultivators who cannot afford them at present. Furthermore, states Ignatieff, increased agricultural production may be of such national importance that a subsidy on fertilizers may be considered a national advantage.

Ignatieff's statement concerning the postponement of fertilizer experiments is misleading. Experiments have been carried out in almost every country in the world where paddy is grown, and although much of this experimental work cannot be statistically examined under modern methods, had the results been strikingly in favour of manuring (as might be expected with a crop grown on the same land yearly over a period of centuries) either experiments would have been continued or manuring would have become commonly employed. It is agreed, however, that the need of further experimentation is most desirable.

The paddy crop removes from the soil considerable quantities of plant food, and no completely satisfactory explanation is as yet forthcoming as to how soil fertility is maintained in the absence of manuring. The proportion of straw to grain and husk is roughly 5:4. According to Sampietro[225] this ratio depends on variety, manuring, climate, temperature of irrigation water, time of harvesting, the soil, the ratio increasing with large fertilizer applications. On the other hand, Haigh[95] states that the relationship between the amount of grain and straw is not seriously affected by spacing or by type of soil. That the amount of plant food removed by the crop varies widely under different conditions is shown by the figures given by the following three authorities. Jack[122] states that a crop of 2,800 lb. paddy removes (in lb.) the following: with the straw, 24·5 lb. nitrogen, 2·5 lb. phosphoric acid, and 60 lb. potash; with the paddy are 42 lb. nitrogen, 9·5 lb. phosphoric acid, and 10 lb. potash. According to Sahasrabuddhi[223] the paddy crop removes an average of 28 lb. nitrogen, 20 lb. phosphoric acid, 60 lb. potash, and 28 lb. calcium. Wickizer and Bennett,[271] quoting from Camus,[41] state that an average production of 1,550 lb. paddy per acre removes from the soil approximately 20 lb. nitrogen, 10 lb. phosphoric acid, and 5 lb. potash, while a similar amount of straw contains about 11 lb. nitrogen, 2·5 lb. phosphoric acid, and 28 lb. potash.

In many regions in Asia the straw is not removed from the fields, but in other cases it is removed and put to various uses. The removal of straw depletes the land of considerable quantities of plant food.

FERTILIZING THE NURSERY

In most countries experiments in fertilizing the nursery have shown that the practice does not result in higher yields of paddy. In India, Sethi[232] sums up the experimental work in that country by stating that at most centres no advantage was found as a result of the practice, although in a few places useful results were obtained by the production of healthier and more vigorous seedlings with better-developed root systems, but the yield from manured and unmanured seedlings did not show significant difference except when some adverse climatic factors, such as drought, set in, when the crop raised from manured seed beds showed better performance. At Bogra (Bengal) manured seed beds showed better growth of the seedlings than the unmanured beds and the seedlings from the former beds were ten to fifteen days ahead of the seedlings from the untreated plots. This result is considered of importance in places where cultivators' seed beds are washed away by floods.

In the Philippines experiments showed that in general plants fertilized in the field gave a higher yield than those unfertilized, or fertilized in the seed bed alone. Fertilizing both the seed bed and the field increased the yield more than fertilizing the seed bed alone.[239] In Spain[39] the seed bed, which may be situated miles from the paddy-field, receives a heavy dressing of fertilizer. In Malaya[92] an experiment showed that the yield from seedlings from an unmanured nursery was actually higher than that from a manured nursery.

While experiments have usually failed to show that there is any advantage in manuring the seed bed, the very great care taken in China and Japan in supplying the nursery with heavy applications of fertilizer must not be overlooked (see pages 117 and 118). In Japan,[208] ammonium sulphate and other fertilizers are mixed with the soil before the seed is sown. More nitrogen should be applied to the seed bed, it is claimed, in cold regions than in warm regions. The recommended amounts per square metre of seed bed are 22·5 grams or more in cold regions, 8 grams in temperate regions, and 4·5 to 6 grams in warm regions. For all regions the phosphate application is about 12·5 grams of phosphoric acid per square metre, and the potash about 13·5 grams (K_2O) per square metre. In Burma,[114] cultivators use cow dung at the rate of about 20 to 25 tons per acre in the nursery.

One may conclude that while fertilizing the seed bed may give increased yields in some areas, particularly in cold regions, the results are not comparable with the manuring of the crop in the field.

RESULTS OF EXPERIMENTS

A vast number of experiments have been carried out in many countries, most of which, unfortunately, appear to be unrelated to soil analysis,* so that comparisons are difficult to make, while many of them were designed in such a way that they cannot be critically examined. The results, however, have a local value and undoubtedly serve to stress the fact that practically throughout Asia manuring would materially increase yields.

Burma

Experiments over a number of years showed that nitrogen and phosphates are the main constituents required. The addition of potash was found to give no increased yield. The results of manuring with different quantities of ammonium phosphate fertilizers containing about 20 per cent phosphoric acid are summarized as follows:

Fertilizer lb. per acre	*Increase in grain lb. per acre*	*Increase in grain per lb. of fertilizer applied*
50	400	80
100	650	65
200	1,100	55
300	1,400	46
400	1,600	40

It was found that the best time to apply the fertilizer is just before the crop is sown or transplanted. Preparatory to the application, the water should be drained off the land and the fertilizer incorporated into the soil by going over the land with a harrow.

Thailand

Phosphates appear to be the chief deficiency in Thailand, although small dressings of nitrogen also seem to be effective. The phosphate is usually applied in the form of ground rock phosphate and the nitrogen in ammoniacal form. It is said that the general increase in yield is about 15 per cent. The opinion is expressed that much of the low yield on the Central Plain is due to poor drainage and the high acidity of the soil. Liming alone gave large and profitable increases

* Ignatieff,[114] however, has recently collected valuable information on the response of paddy to fertilizers together with notes on the soil types on which the trials were conducted.

up to a certain point, but liming to the stage of alkalinity resulted in decreased yields.

INDONESIA

Phosphates on many soils give large increases of crop, the area deficient in this element being given as over a quarter of the total paddy area.

CEYLON

It is stated that phosphate is most needed on the average wet-zone paddy soils, but nitrogen and potash are essential on the light and dry-zone soils. The quantity of nitrogen required is between 20 and 30 lb. per acre in the form of ammonium sulphate, applied at the final levelling before sowing, or preferably in two dressings, one at the final levelling and the second a month later. One hundredweight per acre of superphosphate should be applied with the nitrogenous fertilizer at the final levelling.

INDO-CHINA

Potash alone or in combination with nitrogen has not been found very effective, and nitrogen alone has been found to increase yield but slightly. The combination of phosphate and nitrogen, however, has been found to produce large increases in yield, as much as 50 per cent in the initial season and 30 to 20 per cent in the following two seasons. The Rice Bureau recommends the application of 9 to 18 lb. nitrogen as ammonium sulphate and 36 lb. phosphoric acid per acre.

INDIA

The application of phosphate in the form of bone meal has been found particularly useful in the acid soils of Assam, and has greatly helped the extension of the paddy area in the Khasi and Jainter hills,[232] but in a soil of pH 8 bone meal gave no significant increase of crop.[255] On light soils phosphorus is the limiting factor where there is no response to nitrogen alone.[62] Mineral phosphate, ground as finely as possible, is a suitable phosphatic manure when applied with decomposing matter.[238] Sethi[232] in summing up the experimental work in India states that both nitrogen and phosphorus tend to give increased yields, but the optimum rate of both manures seems to be different in different places, as might be expected in such a vast area. In Bihar, increased quantities of phosphoric acid are of no advantage to the crop unless the quantity of nitrogen is also increased considerably, the most favourable balance being in the ratio of 1 : 1. In the United Provinces, higher quantities of nitrogen

in the presence of phosphoric acid are found effective. In Hyderabad the application of nitrogen and phosphoric acid in the ratio of $1:\frac{1}{2}$ appears to be the most suitable for the *rab* crop, while the ratio of $1:1\frac{1}{2}$ is most suitable for the *kharif* crop. In another series of experiments[104] nitrogen proved very successful in Bengal, the optimum dressing being 120 lb. ammonium sulphate applied at transplanting.

MALAYA

Experiments in Malaya showed that there appears to be a correlation between manuring and tillering, but none between tillering and yield, i.e. increases as a result of manuring have occurred in both tillering and yield but without causal connection. Except on very poor land, the response to artificials has been disappointing, usually insignificant or uneconomic. Exhaustive tests, carried out over a number of years and in different parts of the country, showed that for each area there is a maximum yield beyond which manuring gives no increase of crop. Were it not for the existence of small patches of land regularly giving yields of about 4,400 lb. per acre of paddy, it might be assumed that climatic conditions preclude yields of the order of those obtained in Japan, Spain, and Italy.[28A]

CHINA

The area over which paddy is grown in China is so great that no generalizations can be made regarding manuring. Manuring is intimately connected with the various operations of cultivation. The general practice is to manure the nursery and also the field. The manures used are generally those most easily obtained locally, such as dried cow dung, bone meal, and peanut cake, and the well-to-do also employ ammonium sulphate. Gourley[86] states that there appears to be no exact relationship between yields and the amount of fertilizer used. He continues: "The most exhaustive use of fertilizers would certainly increase the production of rice in China but would not greatly affect the variations between different localities as in many cases there are limiting factors of greater importance than fertility. A district which produces heavy crops does not indicate a liberal use of fertilizers. It is often due to the suitability of conditions in general for rice growing."

JAPAN

The increase in yields of rice in Japan in recent years as a result of research work in various directions, and in no small measure to intensive manuring, has been spectacular. In this connection the value of research work on varieties should not be forgotten, while

improved drainage and irrigation have contributed to these high yields. In support of this contention, the general use of large quantities of manures was practised in Japan before this striking increase in yield took place. Doubtless, subsequent investigations resulted in improvements in manurial practices, particularly in respect to time of application, but they have also been directed to greater knowledge of the economic use of artificials to supplement the natural manures already employed, rather than to replace them. The recent difficulty experienced in obtaining sufficient artificials has renewed interest in the local sources of organic manures. The large amount of humus applied to the crop is to be noted, applied in the form of "natural" manures that are carefully collected and conserved, together with such by-products as fish waste, soya bean cake, and other cakes.

Field experiments have recently been summarized.[207] Nitrogen is by far the most important fertilizer influencing grain yield of both "wet" and "dry" paddy. Phosphorus and potash also have important influences on yield, especially on "dry" paddy. Optimum applications of these nutrients for "wet" paddy range from 55 to 110 lb. per acre, 20 to 55 lb. phosphoric acid, and 35 to 70 lb. potash. Experimental results obtained from ten stations throughout Japan show that yields from plots receiving no fertilizers averaged 54 per cent of the yields from plots receiving complete fertilizer (nitrogen, phosphates, and potash). When phosphorus and potash were added, but nitrogen omitted, yields were 59 per cent of those completely fertilized. Yields averaged 94 per cent when only potash was omitted from applied fertilizers.

The effect on yields of "wet" paddy from varying amounts of nitrogenous fertilizers indicates only small yield increases when more than 100 lb. per acre was applied. Additions of increasing amounts of phosphorus have but little effect on raising yields above those obtained from the smallest application of about 18 lb. per acre of phosphoric acid. Further, yields are not materially raised by increasing applications of potash above 18 lb. per acre.

The Near East

Experiments on lateritic soils of the Yellow Earth type at Lenkoran in the province of Azerbaidjan on the Caspian Sea[164] showed that nitrogenous manures were the most important, ammonium sulphate, urea, and calcium cyanamide being the best.

Egypt

Paddy is grown on both light and heavy clay soils. Manurial experiments in the Sharqia Province, where the soil is of a sandy

nature, showed that some of the Delta soils are very deficient in phosphate, while increases from the addition of nitrogen are also found to be economic. Increase from phosphate application in one case was as much as 60 per cent.

ITALY

In Italy, very heavy manuring of the crop is usual. For example, for paddy-land planted for the first year after grass, 4 cwt. basic slag or superphosphate and 1 cwt. sulphate of potash may be applied per acre; in addition, after the crop is established and after the first weeding, $2\frac{1}{2}$ cwt. per acre of superphosphate, $\frac{1}{2}$ cwt. sulphate of potash, and 1 cwt. ammonium sulphate may be applied.[250]

UNITED STATES OF AMERICA

Fertilizer experiments in which nitrogen, phosphate, and potash have been applied singly and in combination at seeding time, at the experimental stations in the southern States, have not as a rule shown consistent or marked increases in yield. In the three most important States of the south, the results of applying fertilizers are so uncertain that it is recommended that preliminary tests should be carried out to determine whether nitrogen, phosphate, or both, are likely to be profitable. In California fertilizers are widely used and experiments indicate that their use may be justified. The application of ammonium sulphate at the rate of 100, 150, and 200 lb. per acre, of dried blood at 160 lb., of cotton seed meal at 280 lb., and of dung at 1 ton per acre, applied just before seeding, gave profitable increases of crop.

For the mid-season variety Caloro, ammonium sulphate at 150 lb. per acre, and for the early-maturing variety Colusa 200 lb. ammonium sulphate per acre gave the best results. The official recommendation is that granular ammonium sulphate at 150 lb. per acre be applied at seeding time, and many growers have found this practice profitable. Whitlow[270] reports that the fertilizer Aerocyanamide, containing 20·6 per cent nitrogen, has been successfully applied by plane at 100 lb. per acre. He recommends that the application be made when the paddy is four to eight weeks old, and when both ground and paddy are dry (no dew). The field should be flooded after the application.

FERTILIZER PRACTICES

The results of experiments in Asia have found no general application in practice. In Burma and Thailand the manuring of the crop is unusual. In China some artificials are employed by those who

can afford them, but the amount used is small in comparison with the total area cultivated. In Ceylon, Malaya, India, Indonesia, and the Philippines, artificials are little employed. In Indo-China their use is well known and their employment extending. During 1938 27,000 tons were distributed, increasing to 40,000 tons in 1939. The country is fortunate in the possession of local sources of supply. The use of fertilizers in Egypt is not common, and where paddy is grown for the reclamation of saline land no manuring is done. Most of the land in the Nile Delta is heavy clay, and the value of manuring such land is becoming more widely recognized, as the old idea of the fertilizing value of the Nile silt has been found to be much exaggerated.

In the United States there is no regular system of fertilizing the paddy-fields, reliance being placed on the fallowing of land after a few crops of paddy have been removed. Interest in this subject, however, is increasing, since the farmer finds that while new fields are very productive, the yield of successive crops decreases to a marked degree, due perhaps not to lack of plant food but to such causes as increase of weeds, deterioration of the physical condition, lack of humus, unfavourable conditions for the soil micro-organisms, or to other causes.

There remain, therefore, Japan, Spain, Italy, and Australia where heavy dressings of artificials are regularly applied. As producers, all these countries except Japan are relatively unimportant, the crop being grown in restricted areas most favourable for the crop. The importance of Japan, however, lies in the fact that paddy is grown there on a large scale within a wide range of latitude, climate, and soils. Leonard[139] states that much use is made of manures, both natural and artificial, the fields receiving 58 to 135 lb. per acre of nitrogen, 35 to 90 lb. phosphoric acid, and 50 to 100 lb. potash—not, of course, all in the form of artificials. Ammonium sulphate, calcium cyanamide, superphosphate, potassium sulphate, and potassium chloride are, however, in great demand.

In Formosa, the Japanese used great quantities of artificials, particularly ammonium sulphate, to overcome the exhaustive effects of double cropping on a naturally poor soil. Before the war, Formosa probably consumed more nitrogenous fertilizers per unit of area than any other country in the world. About 1 cwt. ammonium sulphate was usually applied to the nursery shortly before seeding. In addition to natural manures, 1 to 2 cwt. per acre of ammonium sulphate and superphosphate, or mixed artificials, were usually broadcast just before transplanting, but usually half or more of the ammonium sulphate was applied as a top-dressing two or three

weeks after transplanting. The second paddy crop was less heavily manured and in some districts given nothing—with consequent smaller crops.

Before the war, an annually increasing proportion of the fertilizer requirement of the crop was supplied as artificials; difficulties in obtaining supplies in post-war years has necessitated greater reliance on natural and local sources of organic manure.

Under the Japanese, rice production in Korea was greatly expanded in post-war years by the use of fertilizers mostly produced in North Korea, but also imported from Japan, and used on the great paddy-growing areas of South Korea. Post-war reduction of imports of fertilizers, coupled with inability of obtaining supplies from North Korea, have seriously affected rice production. Imported fertilizers have been supplied to growers at subsidized prices in order to stimulate rice production. Before the war, ammonium sulphate was applied just before transplanting. At the end of the war no ammonium sulphate was available and imports were mainly ammonium nitrate. The advisers to the South Korean Government found that if ammonium nitrate is applied in three or four applications as top-dressing after transplantation, the increased yield, per unit of nitrogen, is equal to that obtained from ammonium sulphate. They proved this point to the Koreans, and by 1948 ammonium nitrate was widely used on paddy-lands.[76]

In passing, it is noted that the countries that use the heaviest dressings of artificial manures are usually sub-tropical countries that either obtain more than one paddy crop a year or grow a rotation of annual crops in which paddy is included perhaps about one year in four. Caution is therefore necessary in comparing fertilizer practices in these countries with regions in the tropics where one paddy crop is grown annually, and where the paddy area is planted with that crop annually.

TIME OF APPLICATION OF FERTILIZERS

In general, it would appear that when heavy dressings of fertilizers are applied, the most satisfactory results are obtained by applying part shortly before transplanting, and part as a top-dressing about a month later. The top-dressing is usually applied after removing water from the land, the water being readmitted soon after the fertilizer is applied. This process implies a degree of water control rarely possible in most paddy areas in Asia.

In India[232] the most suitable time for application varies in different localities; while in some places the application at different

times does not show any effect, at others it shows a marked difference. Also in some places the total quantity applied at one time seems to do better than its application at two or three times and *vice versa*.

Time of application has been closely studied in Japan. The following recommendations for various climates, soils, and paddy varieties have been laid down in that country.[208]

TABLE 7

RECOMMENDATIONS OF TIME OF APPLICATION OF FERTILIZERS FOR VARIOUS CLIMATES IN JAPAN

Climate	*Soil*	*Paddy variety*	*Percentage of total nitrogen for crop*			
			Basic application	*Application of top-dressing*		
				First	*Second*	*Third*
Cold	Clay	Early maturing	80	20	0	0
Intermediate	Loam	Intermediate	50	25	25	0
Warm	Sand	Late maturing	30	20	20	30

The first top-dressing is made twelve days after transplanting, the second twenty-four days after transplanting, and the third application forty-eight days after transplanting. Top-dressing with nitrogenous fertilizers normally takes place twenty-four days before the paddy heads. On a fertile field the application is sometimes delayed until about a fortnight before heading. When calcium cyanamide is used as a top-dressing about 50 to 100 parts of soil are mixed with one part of the fertilizer, piled into a heap, and moistened with water. The mixture is applied after decomposition of calcium cyanamide, indicated by cessation of heat evolution, is completed. Alternatively, several parts of wet soil are mixed with one part of calcium cyanamide, the mixture being applied immediately between the plant rows, care being taken that none should fall on the paddy leaves. The toxic effect of calcium cyanamide[2] on paddy results in decreased vegetative growth but increased yield.

FERTILIZER REQUIREMENTS OF ASIA

The Rice Study Group at the Baguio Rice Meeting in 1948 appears to have accepted the principle that the paddy crop in Asia is in need of increased quantities of fertilizers, though indeed they

did recommend "that more experimental work be carried out by the rice-producing countries to determine the most efficient practices with respect to kinds of fertilizers, rates of application, time and method of application, and the use of chemical fertilizers in combination with organic manures." Further, the F.A.O. Report of the meeting states: "There is no doubt that fertilizers are not utilized as they could be in the rice-producing countries. Experimental data are still lacking in most of these countries with regard to the efficient use of the various nitrogenous fertilizers with the exception of ammonium sulphate. Nor has the question of phosphate fertilizer received the attention it deserves. Mere lack of response to phosphate, for example, should not be a deciding factor as to its value. More critical experiments are necessary with regard to methods of application when used with a pulse crop grown in rotation with rice. The application of a balanced fertilizer treatment with nitrogen, phosphoric acid, and potash should receive more consideration."

It must be remembered, however, that no complete answer is forthcoming as to how the plant obtains its requirements of nitrogen, phosphate, and potash with continual cropping over a period of years. The question is not answered by assuming that a low level of productiveness has now been reached, "a level at which the plant food removed by the annual crop is made good by the natural breakdown of the soil." The response to manuring in these countries of low yields is so conflicting that it is evident that before a further series of manurial trials are laid down, research is indicated towards correlating soil types in relation to yield, and a study of the reasons for the successful growth of paddy on the same land over a number of years.

ORGANIC MANURES

Cultivators in Asia, especially in China and Japan, have for long made use of waste products for the manuring of their paddy-fields. In the United States also, organic manures are recognized as invaluable for paddy. This opinion is officially expressed as follows: "Usually the soil nitrogen can be maintained by turning under organic matter, such as rice stubble, green manure crops, weeds, and other organic materials. In soils well supplied with organic matter, the decomposition of this material under submerged conditions usually liberates sufficient nitrogen as ammonia to meet the requirements of the rice plants."[80]

In China[252] use is made of every conceivable source of manure. Waste is not thrown on the land without treatment or discrimination, it is carefully matured before application. In north China,

night soil is composted under anaerobic conditions in the process of which much nitrogen is lost; in western China the composting is carried out under aerobic conditions, with little loss of nitrogen. The north China method consists of composting in pits, into which all kinds of refuse material are thrown—human excreta, decayed vegetables, wood and straw ash, animal manure, and the like. Pigs wallow in this mixture and add their excreta. Soil is added and after several months the resulting compost is ready for use. In the western China method, carried out under aerobic conditions, more waste matter is added, so that the carbon-nitrogen ratio is nearer the ideal of 30 : 1.

Organic manures contribute largely to the success of paddy cultivation in Japan. Farmyard manure is usually applied before irrigating, compost before planting. The materials chiefly used in making compost are rice straw, barley straw, plant residues, grasses, sea-weed, night soil, farmyard manure, silkworm excrement, and inorganic fertilizers may be added to provide additional nitrogen for micro-organisms. The recommended application is about 1,000 lb. per acre.

Night soil is also largely used in Japan. It is usually stored for varying periods of time, depending upon the season. To hasten the breakdown of solids a few handfuls of powdered soya bean meal are sometimes added, and the addition of 3 to 5 per cent of superphosphate is recommended to prevent loss of ammonia. When the ripened night soil is applied at planting time it is seldom diluted, but when applied as a top-dressing it is diluted by the addition of from one to three parts of water.[208]

Cattle manure is generally considered the most satisfactory form of organic matter for the paddy crop, but it is usually not available in sufficient quantities and more often than not, in the tropics, has been stored with so little regard for its fertilizing value that much of its nitrogen is lost. On light loams in Ceylon, manurial trials pointed to the need of organic matter, and in every instance where green manure or cattle manure was applied significant increases of yield were obtained. It was found, however, that applications of cattle manure in excess of ten tons per acre were uneconomic.[185] Trials in Lower Burma[103] showed that cattle manure supplying 70 lb. nitrogen gave a five-year increase over controls of 68·7 per cent, while the residual value of the dressing was 37·7 per cent greater than the controls.

GREEN MANURES

Paddy soils are, as a rule, deficient in organic matter on account of the high temperatures and available moisture causing rapid

decomposition of organic matter in the soil. The addition of organic matter to paddy soils not only enriches by reason of added plant foods, but materially improves the physical condition of the soil.

The decomposition of green manures under anaerobic conditions such as obtain in inundated paddy-fields is brought about by micro-organisms (see page 173). Under submerged conditions ammonia and not nitrate is formed as the nitrogenous end-product. Joachim[285] summarizing his previous work[126] on the decomposition of green manures in paddy-fields, states that as a result of incorporating the green matter at time of puddling the land, i.e. *late*, large quantities of ammonia are made available to the soil at all stages of the decomposition process coinciding with the period of crop growth, the maximum being obtained in about four weeks from the time of puddling. "By *early* green manuring," he continues, "i.e. ploughing-in the green manures when the soil is semi-dry, large quantities of nitrates are formed. On subsequent flooding and puddling of the soil these are lost as free nitrogen, leached in the drainage water, or reduced to nitrites which are injurious to paddy seedlings if present in excess. The amounts of ammonia found in *early* green-manured soils are very much less than those found in *late* green-manured soils. By *late* green manuring of paddy soils their nitrogen contents can be maintained or even increased. *Early* green manuring results in large losses of soil nitrogen. No nitrates are found in paddy soils after they have been puddled, nitrates present or added before puddling being denitrified or converted to nitrites."

Whenever possible, the organic matter should be added by cultivating and ploughing in a leguminous crop grown between the paddy seasons. But however desirable it may be to plough in a cultivated crop, in many paddy areas the cultivation of such crops is impossible owing to the nature of the soil, or to climatic conditions. The harvesting of paddy usually coincides with the end of a rainy season; stiff clay soils, so characteristic of vast areas of paddy-land, dry out completely and crack, and are so hard that cultivation is impossible, while any green manure crop grown before this condition is reached would be unable to grow through lack of moisture and the impervious nature of the soil. This is the experience in Lower Burma, and similar difficulties are experienced in many other countries.

Experimental evidence supporting the practice of green manuring is considerable. In Louisiana[197] the addition of leguminous organic matter was found to be the most effective treatment for the improvement of the physical condition of the soil. From the Soviet Union[47] it is reported that peas, ploughed in green in the spring at the rate

of about five tons per acre, before the paddy was sown, increased yields by 23·65 per cent over the control. It was noted that tillering was increased on the green manure plots. In Indonesia[85] it was found that improvement in nutritive value and considerable increases in yield were obtained through green manuring, though the effect varied with the variety of paddy grown. The vegetative period of the paddy crop was shortened, indicating, it is suggested, that the green manure supplied nutrients other than nitrogen. *Crotolaria* spp. were the best as green manure. Soils with a deficiency of humus, and soils containing insufficient nitrogen, gave the best results from green manuring. This is especially noticeable on the young volcanic ash and sandy soils and also on both young and old laterite soils. Lime marl soils, with a deficiency of phosphate, also respond favourably to green manuring. Ossewaarde[176] found that the green manure should be turned in about ten days before planting the paddy; Van de Goor,[85] working with older, lignified material, found that the crop should be turned in about two to four weeks before planting paddy. In many of the experiments it appeared that green manure can be a substitute for other fertilizers such as stable manure and artificial fertilizers.

Mudalier[166] in India states that following the application of green manure to paddy annually for several years in Madras, the yield of paddy had risen to about 2,500 lb. per acre. In China, Hwang and others[112] found that compost was more effective than green manure in improving yields, both of straw and grain; and the residual effect of both was considerable.

The practice of green manuring is carried out extensively in some Asiatic countries. In Japan[208] Chinese vetch (*Astragalus sinicus*) and soya beans are most usually employed for this purpose. The green manure crop is ploughed in after it has been cut and dried for two or three days. Misu,[163] however, found that green manures showed lower availability of nitrogen and lower yields than did soya bean cake and ammonium sulphate, and that the availability of nitrogen was lower in dried than in fresh green manure.[162] In Japan, Chinese milk vetch is broadcast over the paddy-fields. When planted for the first time the seed may be inoculated with nodule bacteria (*Rhizobium* sp.). After planting, the fields are kept well drained and in cold regions about a ton of straw is scattered over the field as a protection for the young plants during winter. The crop is fertilized and yields usually range from about eleven to fifteen long tons per acre. The crop[139] is ploughed under one or two weeks before the paddy seedlings are transplanted in the spring. As soon as the green manure crop has been ploughed in, irrigation water is

run on the land to prevent loss of nitrogen through aerobic action.

In Burma, although the cultivation of green manure is usually impossible, the soil at the beginning of the monsoon is submerged so quickly that the only plants that can be raised at that time are the semi-aquatic grasses which come up naturally and are ploughed in. The value of the weed growth to the subsequent paddy crop is considerable, as is also the paddy straw. It is evident that unless the burning or removal of paddy straw is essential as a means of controlling pests, it is best left on the field to be ploughed in.

In India and Ceylon, the planting of green manure crops has for long been practised where possible, *Sesbania aculeata* being the most popular crop for this purpose. Sunn hemp (*Crotolaria juncea*) and green gram (*Phaseolus Mungo*) and wild indigo are also grown where circumstances permit. Lord[213] has shown in Ceylon that large increases in crop yield of both grain and straw have been obtained through the incorporation of green manures into the soil one to two weeks before puddling (under anaerobic conditions). He recommends that with large dressings 1 cwt. superphosphate and with small dressings ½ to 1 cwt. ammonium sulphate be added. Further, where weed growth is poor, the application of inorganic manures should invariably be accompanied by at least a small dressing of green manure.

Paul[184] in Ceylon has suggested the possibility of planting the pith plant (*Aeschynomone aspera*) as a green manure, as it can grow in standing water, and in fact, its economic value in the manufacture of pith hats depends on that part of the stem which is submerged. In India and Ceylon it is also customary to collect green-stuff from outside the paddy-fields and apply it before planting. It would seem that this practice might be more widely adopted in countries where it is found impossible to cultivate green manures on paddy-fields. In the Jaffna Peninsula in Ceylon, for instance, it is common practice to bring large quantities of green-stuff from the jungles or from wild trees growing on the small islands adjoining the peninsula by train, cart, and boat for the manuring of the paddy crop. Molegode[165] states that the leaves and twigs are carted to the fields in Ceylon before the second ploughing and allowed to decay before being ploughed in. Paul[184] recommends *Glircidia maculata* for planting along the high-land boundaries of the fields, and for the low zone, *Carbera odollam*, as it can stand wet conditions of the soil and makes a good fence. He also suggests *Titonia diversifolia*, the wild sunflower, which produces much leaf and makes a good hedge. It was found that green manuring gave its maximum effect if applied under anaerobic conditions (i.e. after the land has been flooded)

and within a few days of broadcasting or transplanting. An application of five tons an acre gave an increased yield of thirty bushels.

Italian paddy cultivators make great use of green manures. In the Philippines legumes are grown for this purpose. In Egypt berseem or clover is sown while the paddy is ripening; after harvesting the paddy the clover is cropped, often more than once, and then cattle are allowed to feed on the clover. Burr clover is grown in California as a green manure. In one experiment, after ploughing in a crop of burr clover, the yield of rice was increased by about 38 per cent over that from fallowed land.

The choice of green crop must depend on local conditions, but it is suggested that very much greater use might be made of wild plants growing in the vicinity of the paddy-land.

FERTILIZERS WITH ORGANIC MATTER

Desirable as is the increased use of artificial fertilizers, they are beyond the means of the majority of Asiatic cultivators, particularly so if employed in quantities recommended to produce optimum crops. There remains, however, the possibility of using fertilizers in conjunction with such local organic matter as may be available. The evidence in favour of so using fertilizers should be considered the immediate objective of organizations investigating ways and means of rapidly increasing the production of rice in Asia.

This combination of inorganic and organic manures has been tested in many regions. At Karnal, India, Parr[183] showed the following increases of yield: 120 lb. bone meal, 10·5 per cent; bone meal and farmyard manure at 40 lb. nitrogen per acre, 21·6 per cent; ammonium sulphate at 40 lb. nitrogen per acre, 18·1 per cent; ammonium sulphate and bone meal, 29·0 per cent. Chang and others in Formosa[43] showed that stable manure, and to a less extent soya bean cake, maintained fertility and was more effective for the later than for the earlier crops over a twelve years' experiment. Green manure gave the highest yield during the first few years, but this effect was not maintained. A complete inorganic manure was inferior to green manure, but with the addition of lime the yield was greatly increased.

In Mysore[267] it is considered that artificial fertilizers are less efficient than green manures, while the efficacy of either class of manure can be considerably improved by combining them. Hwang and others[112] in China recommended compost, with a top-dressing of ammonium sulphate, the latter promoting the decomposition of the compost and green manure. Richardson[218] and his colleagues in

China stated that the fertility of the alluvial paddy soils, such as those of the Changto Plain, can be maintained or even increased by the use of compost or green manure instead of compost, if supplemented by a moderate dressing of inorganic nitrogenous fertilizer.

In Ceylon[160] there was an improvement in yield from the application of small amounts of green organic matter in conjunction with bone meal. The free issue of bone meal in Ceylon is conditional on the application by the cultivator of a stated amount of organic matter. Experimental work in India[232] has also demonstrated the useful results of combining organic forms of nitrogen such as green leaf, cakes, and cattle manure with inorganic forms of nitrogen such as ammonium sulphate, while the use of lime and bone meal proved to be useful adjuncts to green manuring in India.[235]

Yields in British Guiana are high, approaching those obtained in Japan, yet manuring is unusual. Experimental work in that country indicates that higher yields are possible and that the highest returns are obtained when green manuring is followed, seven months later, by the application of ammonium sulphate in conjunction with superphosphate.[203]

OXIDATION-REDUCTION ZONES IN WATERLOGGED SOILS

Instances may be multiplied of the varying response of soils to the application of fertilizers, the results being so conflicting as to offer no basis for a generalized statement of the manurial requirements of the crop. Admittedly, the difficulty may be accounted for in part to incomplete knowledge of the soils upon which the manures were applied.

A new scientific approach is needed to this problem, and in this connection the work of Pearsall on oxidation-reduction zones in waterlogged soils provides a basis for study on the problem from an entirely new and more scientific angle than has hitherto been possible.

In brief, Pearsall and his co-workers found measurable differences in oxidation-reduction potential in waterlogged soils, oxidation taking place in the surface layer of the soil and reduction at lower levels. Pearsall has outlined[187] the concept of oxidation-reduction zones and the measurement of electrical potential in soils ranging from forest to waterlogged or submerged soils. At about 320 to 350 millivolt there is a change from oxidation to reduction conditions in submerged soils. He suggests that relatively low oxygen concentration suffices to maintain predominantly "oxidizing" conditions, and states that it appears probable that organic matter, or some associated system present in the soil, may exert a "poising action'

which assists the establishment of an approximate stable potential at the lower ranges. The chemical properties of soil organic matter (including base exchange properties) are much affected by oxidation or reduction, if not mainly determined by these conditions.

Appreciation of the existence of oxidation-reduction zones in paddy soils leads to the study of soil reaction from three points of view, viz. cultivation, manuring, and plant growth.

Cultivation

The cultivation of seasonally waterlogged soils involves three principles—those controlling the seasonal development or reducing zones, the effect of these on mineral availability, and their effect on biological systems in the soil. The rate of development of the reducing zone and the depth of the zone below the surface depends on the amount and type of organic matter and on the soil flora.

Manuring

The Japanese were quick to realize the implications of Pearsall's work in the action of manures applied to the paddy crop, for it explained why certain methods of application were practised, why fertilizers so frequently gave negative results, and suggested new methods of applying fertilizers and the compounds of nitrogen most suitable for the crop. Pearsall has stated the position as follows:

> During the periods when it is submerged or waterlogged a rice soil develops reducing conditions, even though the surface-layer remains oxidizing as long as it is in contact with air or oxygen-containing water. It is therefore common to see a rusty-coloured surface-layer and a blue or blue-mottled soil below whenever the lower layers are exposed. Japanese workers have experimentally confirmed the existence of oxidizing and reducing zones, the depth varying probably with the duration of flooding and other similar conditions.
>
> When a fertilizer like ammonium sulphate is sprinkled on a rice-field, it is affected by the conditions present in the surface or oxidation layer, the sulphate radical remains unchanged and the ammonia is converted to nitrate as in a normal soil. If, however, any part of this nitrate should pass into the lower reducing zone, it is reduced to nitrite and thence to atmospheric nitrogen, which is lost. It has been stated that as much as 70 per cent of the nitrogen applied as ammonium sulphate may be lost in this way, not by leaching. The mechanisms by which the nitrogen is lost are almost certainly of microbiological origin.[22]
>
> If in contrast, ammonium sulphate is trodden or worked into the lower zones of a wet rice soil, the ammonium ions remain unchanged in the reducing zone and are available to the growing crop. Marsh plants like rice have roots that are able to grow and function in reducing soils because they contain internal air-spaces, which carry oxygen internally

to the respiring cells and growing tissues. Roots of this type often have round them a red-brown oxidizing zone and in some cases traces of nitrates have been detected in this "rhizosphere." It may also be mentioned that rice roots raise the oxidation-reduction potential of unaerated solutions.

It will be clear from the above that the success of any particular types of fertilizer will depend partly on the method and place of application. In general, nitrates should be applied only to the oxidizing zone at a time when immediate uptake by the crop is possible. Nitrate that penetrates to the reducing zone is generally lost. Ammonium nitrate has the particular theoretical disadvantage that in contact with reducing conditions it is readily reduced to ammonium nitrite, which may be converted microbiologically to gaseous nitrogen with great ease.[186] Calcium cyanamide has been tried as a source of nitrogen for rice. When it is applied to the surface-oxidizing soil it is acted on (presumably by microorganisms) and is almost quantitatively converted to ammonia in from 5 to 7 days. It can then be mixed with all layers of soil. The best crop yields are obtained by this method. If the cyanamide is mixed with the deeper reducing layers at the time of application, it causes serious damage to the plants, so that it is not very effective in increasing the yield. Apparently the organisms converting it to ammonia require oxygen. An organic material like bean cake is, however, quite effective when applied in the deeper layers. Presumably it is partly broken down to ammonia by anaerobic organisms and retained in the reducing zone in this form.

It must be assumed that ammonium sulphate produces other effects besides those due to ammonia utilization. For example, when ammonium ions are absorbed, sulphuric acid is left and the soil solution may become extremely acid. This must accelerate leaching effects. When ammonium sulphate is added to the reducing zone the sulphate will be reduced to sulphide, which will combine with iron as long as that metal is available, but when iron becomes deficient, hydrogen sulphide or methyl sulphide will appear, both producing toxic effects on the crop-plant. It would appear that as long as the soil is saturated with calcium or iron the toxic effects are likely to be small.[188]

Working along these lines has recently produced favourable results in Japan. Japanese official recommendations now state "that the loss of ammonium-nitrogen through oxidation-reduction in paddy-fieds can be prevented largely if nitrogenous fertilizers are applied deep in the soil. Consequently, nitrogenous fertilizers should be thoroughly mixed with the soil and the field be irrigated within three or four days after application of fertilizers. If considerable time elapses between the time a fertilized field is irrigated and the time rice seedlings are transplanted on it, the loss of nitrogen becomes serious. Farmers are cautioned not to let more than ten days elapse from the time a fertilized field is irrigated until the rice plants are

transplanted. Irrigated fields should be drained before fertilizers are applied."[208]

The effect of deeper application of fertilizers is worthy of intensive study in the light of Pearsall's work. While the practice of applying nitrogenous fertilizers well below the soil surface is already usual in some regions, the possibilities in this direction are by no means exhausted. Recently, for instance, ball-shaped lumps of peat with ammonium sulphate and superphosphate have been applied deeply in the soil, and larger crystals or lumps of ammonium sulphate or oil-covered ammonium sulphate crystals have been suggested. In Louisiana,[268] nitrogen, phosphorus, and potash, each applied at the rate of 24 to 30 lb. per acre, increased yield by about twenty-five bushels per acre, but a top-dressing gave less consistent results than applications below the seed.

The implications of the oxidation-reduction zone on plant growth must be taken into account. It is possible that further study may reveal the explanation of phenomena concerning plant growth which have hitherto remained unexplained.

CONCLUSIONS

More knowledge is required on manuring in relation to soil analysis. Investigations suggest that trace elements in the soil are important factors in connection with plant nutrition. Research in this direction may solve some of the curious anomalies that exist regarding yields in certain areas and might provide a key to successful manuring.

In most countries the paddy crop responds to fertilizers in which nitrogen is present in the form of ammonia, but in some cases a late dressing of nitrate is remunerative. In many soils, the limiting factor to yields is phosphorus, but potash is not, as a rule, required. The response to manuring with artificials, however, varies considerably, pointing to the necessity for further study of the problem.

Most paddy soils respond to the application of organic matter, a form of manuring usual in all countries in Asia in which yields are high. Green manuring, where possible by growing crops between the paddy seasons, has been found most successful; where this is not possible, equally good results have followed the application of green material brought on to the land and ploughed in while in a fresh condition shortly before the crop is planted.

The general trend of manurial experiments has led to emphasis on the supreme importance of organic matter, fertilization with artificials being subsidiary, or at least complementary to, organic matter.

This is indeed fortunate, for unless fertilizers are supplied at subsidized prices, there appears little prospect that they will be widely used by Asiatic smallholders, particularly in the heavy dressings found necessary to give optimum yields where they are applied without also applying organic matter. The smallholder simply cannot afford to purchase expensive fertilizers in large quantities, and the evidence points to the fact that these heavy dressings are unnecessary. There is considerable evidence of the value of organic matter in raising yield levels, and fortunately, organic matter is usually available in overwhelming quantity in many paddy-growing regions. It is often merely a matter of labour in collecting and transporting green foliage to the fields—and labour is of little consequence in many parts of Asia.

Advantage should, therefore, be taken of this ready means of increasing production, and propaganda directed to the methods of utilizing all forms of organic matter to the best advantage, rather than advocating methods of increasing yields which are beyond the means of the great majority of cultivators. If fertilizers are to be used, and their value in many cases is clearly proved, advantage should be taken of their value when applied in addition to, and not instead of, organic matter. Applied in this way, the reduced cost per acre may be within the means of the peasant cultivator.

The time and method of application of both organic and inorganic manures may well be a factor of first importance in the manuring of paddy. It is evident that much of the artificials applied by present methods is wasted. In this connection, the application of the recent work on oxidation-reduction zones in the soil is extremely important, and this should be a new starting-point in the reconsideration of the subject of the manuring of paddy.

Chapter XIII

STORAGE OF PADDY AND RICE

Smallholders' Methods of Storage—Storage at Mills—Causes of Losses in Storage—Effect of Moisture Content of Stored Grain—Control of Moisture in Storage—Storage Temperature—Hermetic Storage—Insect Pests of Stored Paddy and Rice—Pest Control by Insecticides.

SMALLHOLDERS' METHODS OF STORAGE

THE methods of storage of paddy by the Eastern peasant are of the simplest. Provided that the crop is reasonably dry, unhusked rice (paddy) apparently remains in good condition for a considerable period. The writer has examined paddy stored by peasants for four or five years and found it to be in reasonably good condition. Much of the damage to paddy in store, however, is not very apparent until husking, when it may be found that there are a large number of empty glumes. The cultivator invariably stores the crop as paddy, which he husks in small quantities at a time, sufficient to supply current domestic needs. Paddy in excess of his estimated requirements is usually sold soon after harvest to middlemen who in turn sell without delay to the millers.

The paddy store is generally situated at one side or adjacent to the owner's dwelling in a wooden or plaited bamboo shed provided with a plank or round timber floor and a leaf or corrugated iron roof. Sometimes the walls are omitted. The store is raised on piles a few feet from the ground, or on a platform of earth to protect it from damp. The bins in such a shed are usually circular and constructed of plaited split bamboo or, in Malaya, often from a single piece of the bark of the *kepong* tree (*Shorea sericea* Dyer). The bins are covered with a piece of the same bark or with planks. Apparently rats find some difficulty in gnawing through split bamboo or *kepong* bark. In Burma,[201] where plaited bamboo is also mainly used for the construction of bins for the storage of seed paddy, the plaited bamboo is daubed with a mixture of clay and cow dung to prevent the grain from escaping and to exclude rain and rats. The paddy store usually seen in Burma is a rectangular building of plaited

bamboo, with corner posts of wood and a roof of leaves or grass. It is usually built on piles, has a floor of bamboo matting or plank, and sometimes of both, the space between the upper floor of bamboo matting and the lower one of plank being filled with paddy husk to support the weight and to keep out damp. The paddy is stored in bulk and is thrown through a doorway which, as the grain rises, is closed from the bottom upwards by dropping planks into vertical slots in the door posts. Mill godowns (stores) and those of the larger stockholders are usually of corrugated iron, but plaited bamboo is often used in them to divide compartments or for flooring.

A very similar store is used in the northern state of Kedah, in Malaya,[226] where in a good season the cultivator has paddy for sale after making provision for his own needs. The surplus crop if sold at harvest would force down the price; the stock is therefore held, either by private enterprise or by Co-operative Societies, for a period of six to nine months, when it is sold on an improved market.

In Ceylon[184] stocks of between 50 and 300 bushels are stored in a *bissa* made from tough jungle creepers plastered with clay and lime, and placed on wooden or stone pillars. In Lower Burma a large part of the paddy crop is not placed in storage until it reaches the mill. The threshed grain is taken to collecting points, usually adjoining waterways or rail, where it remains in large unprotected heaps in the open during the first three months of the year. Rain damage is extremely unlikely during this period of the year.

The paddy cultivator is usually in need of money and therefore disposes of his crop at the earliest opportunity. Stocks held by cultivators are therefore usually small so that no question of more ambitious methods of storage is presented.

STORAGE AT MILLS

On arrival at mills in the East, the paddy is stored in large godowns where it remains for no considerable time before milling. The miller, therefore, considers it unnecessary to erect elevator storage such as is usual in America where, however, the quantity of grain produced by individual farmers is considerable. In Burma, while it is appreciated that the adoption of elevator storage would facilitate pest control in the grain, it is considered that the cost and other disadvantages of the system outweigh any possible advantages. The aim of the miller is to dispose of stocks before monsoon rains set in. The paddy, therefore, is in a dry condition which gives improved milling and obviates heating and sweating and thereby lessens attack by rice weevils which thrive under conditions of warmth and damp.

The elevator system of storage as practised in many countries for the storage of grain has the advantage that in addition to affecting economies in handling, it facilitates the manipulation of the stock to control insect pests by providing good, dry storage conditions. The absence of up-to-date storage godowns, however, does not mean that rice or paddy cannot be kept in equally good condition. The cardinal factor of storage is that the crop must be well dried before storage. The Asiatic cultivator is usually well aware of the necessity for storing in a dry condition, for he appreciates the fact that apart from rats, practically all other destructive agents arise from excess of moisture. While paddy[123] stored in a reasonably dry condition remains edible for a considerable period under ordinary storage conditions, rice is scarcely edible after eight months' storage, but under rat-proofed and well-ventilated conditions it may be stored for two years.

CAUSES OF LOSSES IN STORAGE

The causes of losses in grain during storage have been summarized by Oxley[177] as follows:

(1) Metabolism of grain tissues.
(2) Metabolism of micro-organisms.
(3) Metabolism of insects and mites.
(4) Metabolism by rodents and birds, causing fouling and loss of material.

EFFECT OF MOISTURE CONTENT OF STORED GRAIN

Moisture content has a profound effect on the first three of the above-stated sources of loss, causing "spontaneous heating," loss of viability, loss of material, and chemical changes. Oxley further points out that the storage life of a bulk of grain is determined by its dampest point, for spontaneous heating can begin with a damp pocket and may initiate heating throughout the bulk. It is thus clear that control of moisture content to reduce losses of grain must include not only control of the mean moisture content, but also control of the distribution of the moisture in the bulk. The exchange of water vapour by diffusion is held to be insufficient to ensure even distribution of water, for a wet pocket may take months or years to equilibrate with other parts of the bulk. The damage of wet pockets is especially to be guarded against in freshly harvested grain. It follows, therefore, that if the homogeneity of water content could be assured, grain might be found to be safe for storage at higher levels of water content than have hitherto been expected.

Oxley[177] states that the spoilage of grain at water content levels above 14 to 15 per cent is largely due to micro-flora, and that fungal micro-flora below the epidermis of the grain is independent of the change spores on the outer surface.

Copeland[51] states that most Californian rice mills do best with about 14 to 15 per cent of moisture, and that finished rice for export cannot get a government certificate of grade if it contains more than 14·5 per cent of moisture. Uncured rice may be expected to sweat in the warehouse, however dry it goes in, but it comes through the sweat without damage if properly dry. The moisture content limits, it has been pointed out by Hukill,[110] are variable for different species of mould and types of insects and also depend upon the storage temperature. With lower temperatures a higher moisture content may be tolerated. It follows that moisture content must be less when storing in the tropics than when storing in temperate climates.

Normally in the East, there is no difficulty in drying the paddy sufficiently by spreading it for a few hours in the sun (at the risk of sun-cracking of the grains), but it is evident that in the storage of paddy, and particularly of rice, in bulk, greater precautions are necessary to obviate the danger of the development of fungal micro-flora.

Fungus flora[127] of stored grain is essentially the same the world over, consisting chiefly of species of *Penicillium*, *Aspergillus*, *Alterraria*, *Fusarium*, *Cladosporium*, and *Rhizopus* and a number of other fungi. The excessive heating of the store of grain is caused by the respiration of the fungi. At moisture temperatures generally above 14 per cent the fungus spores germinate and grow, although some species of fungi are able to germinate and grow at lower humidities and thus cause additional moisture so that other species also become active. Clean, high-quality grain is less subject to attack by fungi than broken or injured grain, for not only is the food material of broken grain more readily available for the fungi, but it absorbs moisture more readily than unbroken grain. Broken grain also encourages the ravages of insects, some of which, in fact, cannot attack perfect grain.

CONTROL OF MOISTURE IN STORAGE

The prevention of high moisture content is the best means of protecting grain against fungus and insect damage, while the efficient ventilation of the grain may also prove efficacious if the air available is drier than the air in intimate contact with the grain. Bulk drying in a stream of untreated air ("Bin Ventilation"), or in a stream of

dried air, are suggested by Oxley. The former appears to have limitations, and depends more on the "cooking effect" rather than the drying effects. For bulk drying in a stream of dried air, the temperature of the air should be raised by about 10° C. When this method is adopted precautions must be taken to obviate an excessively long air path which would result in a bad moisture distribution in the bulk. The efficacy of the Edholm drier[75] depends on the fact that when grain is dried in a series of short periods with relatively long intervals of rest between, the amount of water removed each drying period is greater than with continuous drying, because once the outer skin of the grain is dry, time is needed to enable moisture from the grain to diffuse to the skin. The Edholm drier therefore consists of a storage bin traversed at several levels by layers of air ducts. In each layer, air is blown into alternate ducts and sucked out by others. Dry grain is continually removed from the bottom of the bin and damp grain added at the top, the divisions being so arranged that the grain spends about three minutes between ducts in a stream of air and an hour resting between the layers.

STORAGE TEMPERATURE

Oxley[287] points out that most grain pest insects are of tropical and sub-tropical origin, their optimum temperatures lying between 28° and 35° C., and their maxima (above which they die or at least cannot reproduce) usually between 33° and 40° C. If possible, therefor, grain in store should be kept as far below the optima as possible, or alternatively, at temperatures above the maxima. The latter is considered impracticable, as it would lead to other troubles.

HERMETIC STORAGE

Perhaps the most interesting development in the technique of storage is provided by hermetic storage, by which the grain is absolutely protected from any exchange of gases or liquids with the outside environment. It is claimed that such a store will protect grain from both insects and rodents. It has been found that when carbon dioxide reaches 18 or 19 per cent of the total volume, adult insects, their larvae, and even their eggs are killed. Carbon dioxide is emitted by the live grain in direct relation to the amount of moisture contained in the grain, and also by the respiration of the insects in the grain.

A second point of importance in hermetically sealed storage is that the grain cannot become overheated. Vayssière[261] discusses the

type of hermetic store which is most suitable. As regards the site, the choice between under and above ground depends on convenience, economy, and suitability, which may vary in different localities. Doyère favours the underground site, which he describes as a container made of thin sheet metal, shaped like a bottle, the imperviousness of which has been ascertained. Its opening is closed by a pressure lid. The sheet metal is preserved against oxidation either by zincing or by the application of a thick coating of a tarry varnish. The container is placed in a pit under a concrete form and covered with masonry to support the lateral thrust and the top weight of the ground. The sheet metal only serves as a covering which, while thin, is nevertheless perfectly waterproof, holds up, cannot crack or disintegrate, and can be fitted with one or more hermetic closing devices.

Vayssière sums up the advantages of hermetic storage as follows:

(1) Disinfectants stored foodstuffs by destroying insects, irrespective of their stage of development as well as other pests at the time of storage.

(2) Positively forestalls the admission of insects and other pests.

(3) Forestalls mould and overheating when the product contains a relatively high degree of moisture, without preventing the development of acidity caused by anaerobic fermentation when the humidity is excessive.

(4) Forestalls the absorption at atmospheric humidity. All products that are dry at time of storage remain dry.

(5) Saves time and money by dispensing with handling and shifting.

The ideal method of storage is claimed to be drying, followed by hermetic storage. The widespread adoption of this method of storage would undoubtedly result in a tremendous saving of rice and the improvement of the standard of quality, especially if such precautions against deterioration were made not only in mills and granaries but also—and this appears to be most important—in the ships that carry the grain. Hermetic storage, however, is not suitable for grain destined for seed purposes, as this method of storage would adversely affect germination of the seed. Airtight storage, states Oxley,[287] deserves thorough trial in hot countries provided that the grain can be harvested dry, or where drying facilities exist. He considers that the underground-pit type of store found in the tropics is, in fact, nearly airtight and the success of such stores may be a testimony to the efficacy of nearly airtight storage.

INSECT PESTS OF STORED PADDY AND RICE

Many species of insects attack stored rice and paddy, only a few of which cause serious injury to the crop. Nevertheless, the damage occasioned by them may be very great, damage which is usually preventable or might be reduced by the observance of the simple rules for good storage.

By far the most destructive pest is the rice weevil, *Sitophilus oryzae* L., closely related to the granary weevil, *Sitophilus granarius* L. Other insect pests associated with stored paddy and rice include *Rhizopertha dominica* F., *Sitotroga cerealella* Oliv., *Oryzaephilus surinamensis* L., and *Ephestia kuehniella* Zell. Other insects of less importance may attack damaged grain, decaying grain, or may discolour the product, thus reducing its market value.

Rice Weevils

Both the rice weevil and the granary weevil are small, reddish-brown to dark brown in colour, about one-eighth inch long, with mouth parts prolonged into a snout. The rice weevil is marked on the back with four light-reddish or yellow spots and has functional wings, whereas the granary weevil is without the spots and is unable to fly. The snout is used to bore into the grain to reach the endosperm as well as to excavate a small cavity in the grain in which to place an egg which is then sealed with a gelatinous cap which protects the egg from damage.

In a few days the egg hatches and a small, fleshy, white grub emerges which feeds on the endosperm of the grain until it is fully grown, when it emerges from the grain. By passing the development period within the grain the defenceless immature stages of the weevil are protected from predaceous enemies and sudden destructive changes in temperature. Under favourable conditions the period from egg to adult weevil is about four weeks.

The size of the weevil depends largely on the size of the kernel of the grain; a small grain will be almost completely devoured by one weevil, whereas a kernel of maize will provide food for several weevils, which ultimately will be larger than weevils bred in a grain such as rice.

The rice weevil is of greater importance than the granary weevil because it can fly to the fields and attack the grain before it is harvested.[54]

In the colder countries of Europe the rice weevil usually dies. These two weevils multiply mostly in badly kept mills where grain

residues are left in machinery, and in corners that have been inadequately cleaned.[152]

THE LESSER GRAIN BORER (*Rhizopetha dominica* F.)

Under favourable conditions this pest may cause great damage to grain. During the Second World War it was the principal insect pest in Australian bulk depots, while *Calandra oryzae* (small strain) was the most troublesome in bagged wheat.[77]

The habits of this borer are somewhat similar to those of the rice weevil, except that the grubs can feed outside the kernel as well as inside. The grubs and beetles may completely hollow out kernels so that only the bran coat is left.

Turning and cleaning infected grain is of no value in the control of the pest; in fact, it merely disperses the insects throughout the grain, so that higher dosages of fumigant are necessary to control the attack.

It breeds freely in warm climates, and will also breed and hibernate in mills in the temperate climates of Europe. Mayné states that it is prevalent in Belgian mills, and could easily become in a short time one of the greatest enemies of stored grain.[152]

THE SAWTOOTHED GRAIN BEETLE (*Oryzaephilus surinamensis* L.)

This is a slender brown beetle with six peculiar toothlike projections on each side of the thorax. It sometimes occurs in great numbers in bins of farm-stored grain, but does little real damage since it feeds chiefly on cracked and broken grain. It rarely flies, but walks rapidly. On account of its small size it is able to enter tightly packed food packages.

THE ANGOUMOIS GRAIN MOTH (*Sitotroga cerealella* Oliv.)

This moth is second in importance only to the rice and granary weevils as a pest of stored grain. The moth flies to the fields as the kernels are beginning to form and lays its eggs on the developing grain. The young grubs, or caterpillars, that hatch from the eggs burrow into the kernels and complete their development hidden from view. Before transforming to the pupal stage, the caterpillar makes an escape tunnel to the outside of the seed, leaving only a thin layer of seed coat intact, for the moth to push through as it leaves the grain.

The insect is troublesome only when the harvesting and binning of the grain is delayed. The soft-bodied moths are unable to force their way below the surface of binned grain, so that much of the damage can be prevented by early harvesting.[54]

Mediterranean Flour Moth (*Ephestia kuehniella* Zell.)

This is a pale-grey moth, the larva of which spins threads wherever it goes, thereby webbing the flour together. It is easily controlled by fumigation.

Rust-red Flour Beetle (*Tribolium castaneum* Hbst.)

The rust-red beetle lays eggs in flour and grain, the grubs subsequently feeding on the grain. It is frequently a serious pest of flour mills, but is usually easily controlled by maintaining clean conditions in the mill.

PEST CONTROL BY INSECTICIDES

Fumigants are used for the rapid destruction of insect and other pests throughout a bulk of foodstuff. The aim is to obtain an even distribution of the fumigant in the shortest possible time. The choice of fumigant and the method of fumigation will depend on local circumstances. While the best treatment is in chambers especially designed for the purpose, fumigation may be effectively carried out in the warehouse, and for economy of fumigant by covering the sacks or bulk to be treated with a gas-proofed sheet of rubberized or plastic-coated material and introducing the fumigant below the covering.

The method of treatment of grain will depend on storage conditions. For large bulks, spraying the fumigant above the surface may be effective; for grain stored in silos, liquid or granular fumigants can be mixed continuously or intermittently with the grain stream as the bin is filled, or liquid fumigant can be sprinkled over the surface at intervals during the filling of the bin. A most effective method is to fit the bins with means for circulating the intergranular air so that the fumigant vaporized into the stream of air is rapidly distributed throughout the bin.

The effectiveness of a fumigant also depends on the extent to which it is absorbed by the grain; where absorption is high a larger proportion of the fumigant will be rendered ineffective and the greater the attention that must be given to the eventual "airing" of the grain to rid it of contamination by the fumigant which otherwise may cause a taint, or even render the grain poisonous.

There are many fumigants, varying considerably in their toxicity to insects. The choice may be largely decided by considerations of availability and cost.

Hydrogen cyanide, one of the first fumigants to be widely used to control pests in stored foodstuffs, is highly toxic to man and should therefore be handled only by trained operators. It is still commonly

used, particularly in the treatment of empty warehouses, mills, and the holds of ships.

Carbon disulphide is now little used because of the considerable explosive risk which attends its use. It is, however, still employed in some countries, particularly in the treatment of grain by hand sprinkling, or by spraying through pipes and nozzles.

Chloropicrin, less used than formerly, is used in the "spot" treatment of mill machinery and to control surface infestations in silo bins.

Ethylene oxide is a very effective fumigant, but can seriously affect the germination of seeds. Owing to its inflammability in air, for use it is usual to mix it with carbon dioxide in the proportion by volume of one part of the fumigant to nine parts of carbon dioxide. Burns Brown[36] states:

> In Great Britain since 1940 considerable use has been made of a method of fumigation in which crushed solid carbon dioxide is first distributed above the commodities to be treated and the usual ethylene oxide fumigant is applied after an interval of a half to one hour. The carbon dioxide is usually applied at a rate of 20 lb. per 1,000 cu. ft. of air space, the aim being the production of a concentration by volume of 10 per cent or more. At such concentrations of CO_2 the susceptibility of most insects to ethylene oxide is appreciably increased and the dose of this fumigant can be reduced to a point at which the maximum concentration reached throughout the space as a whole remains below inflammability limit. This procedure greatly reduces, even if it does not entirely eliminate, the explosion hazard. The risk is minimized when it is possible to stir the air in the fumigated space or when the solid carbon dioxide and liquid ethelene oxide are mixed and vaporized into the space using a simple form of heated vaporizer.

Methyl bromide is now one of the most widely used of fumigants. Its toxicity to insects is high and its absorption low. Methyl bromide is, however, highly toxic to man and it should be handled with proper precautions. Chloropicrin is commonly added to the extent of about 2 per cent, as the lachrymatory property of this substance draws attention to leaks in fumigating apparatus or in the compartment being treated.

> Methyl bromide is normally introduced from cylinders through a system of copper or plastic tubing with spray nozzles attached. Advantage can be taken of the high density of the vapour to aid downward penetration into loose bulks of material, and in Great Britain it has been employed for the treatment in barges of bulks of grain.[36]

Aliphatic chlorohydrocarbons are less toxic to insects than the above fumigants, but they are safer and therefore recommended to

those who are not familiar with the application of fumigants. They are, therefore, suitable for fumigating small quantities, empty bags, and for treating grain in farm bins. They are usually applied from a sprinkling can, or by means of a stirrup pump. The most popular fumigant of this class is a mixture of three parts by volume of ethylene dichloride (1,2-dichloroethane) and one part of carbon tetrachloride, used at the rate of 5 gallons per 1,000 bushels of grain. For a large silo it has been added with the grain at the rate of 2½ gallons per 1,000 bushels. Carbon tetrachloride readily penetrates downward through bulks of grain. Frequently it has been used as a carrier for a more toxic compound, such as methyl bromide 10 per cent, ethylene dibromide 5 per cent, chloropicrin 15 per cent, 1,1-dichloro-1-nitroethane 15 per cent. These additions, however, make the fumigant more dangerous to use, consequently they should only be operated by specialists.

Among other fumigants suitable for the treatment of grain may be mentioned methyl formate, used in Germany for treating grain in bins fitted with a circulating system, mercury vapour, and sulphur dioxide.*

Because of their simplicity and cheapness, since no expensive equipment is required, smoke generators are becoming increasingly popular in protecting stored crops against pest infestation. The insecticide from smoke generators is evolved in the form of very small liquid droplets, so small that they are easily transported by convection currents from the generator and natural draughts, and diffuse uniformly. For certain purposes, such as warehouse treatment, smoke generators are of particular value, for whereas there is no residual effect when gases or volatile vapours are used, the solid particles from the smoke generator persist for a considerable time.[45]

Where fumigation is impossible, contact poisons may be used in the form of sprays, smokes, and dusts. Compared with fumigants, contact insecticides are less efficient as they cannot reach insects within packages, or in deep bulks of grain. The most important of the contact insecticides are the pyrethrums, obtained from *Chrysanthemum cinerariifolium*, D.D.T., and B.H.C. The moths and caterpillars in stored grain are more resistant to D.D.T. than to pyrethrum, while some are scarcely affected by it. D.D.T. is, however, relatively cheap, and easily made up into dusts, pastes, and smoke generators.[182] The toxic effect of D.D.T. and B.H.C. imposes a limit to the quantity which can be added to foodstuffs with impunity. It is only safe to

* The above account of fumigants is largely drawn from *Fumigants for Pest Control in Stored Foodstuffs*, by W. Burns Brown, *World Crops*, Vol. 12, No. 6 (June 1950).[36]

use these insecticides in foodstuffs in such a way that certain limits of the insecticides in the foodstuffs are not exceeded. The generally accepted safe limits in foodstuffs are D.D.T. 7 p.p.m.; B.H.C. 2·5 p.p.m. of the gamma isomer, provided that the B.H.C. used contains 12 per cent or more of gamma isomer.

Gamma B.H.C. 14 per cent can be dusted on rice or on the bags for the control of weevils. It has been recommended that 0·015 per cent D.034 (5 per cent gamma) be used, which gives a concentration of 0·000075 D, for seed: with greater concentration there is a danger of taint.

Ghoshi,[82] experimenting with gammexane (666) for the control of insect pests of stored rice, stresses the value of introducing the insecticide as a smoke, not only for convenience but because in this way it can be employed for quick and efficient treatment of stores before introducing sound grain therein. He obtained 100 per cent kill in six days, but found definite signs of reinfestation a month later. The residual effect of this insecticide is therefore not considered to be satisfactory. A 5 per cent gammexane dust is recommended to be applied to the rice in bags, about $1\frac{1}{2}$ lb. being required per 165 sq. ft. of area exposed. When an emulsion spray is used, a rate of 4 litres of emulsion per 165 sq. ft. is recommended.

In Egypt calcium superphosphate has been used for insect control in stored grain. It is said to be satisfactory except under moist conditions. Similarly, the liming of rice in the East has proved satisfactory provided the rice is retained in a dry condition. Squire[247] states that sodium fluorsilicate gives control but that, as there is a prejudice against its use, calcium carbonate is found to be equally effective, and has the added advantages of being cheaper than fumigation and safe and easy to put into effect.

Cotton and Gray[54] discuss the subject of preservation of grains and cereals in storage from insect attack in some detail.* They state: "Rough rice stored in concrete elevators may be fumigated successfully at the following dosages per 1,000 bushels; carbon tetrachloride with ethylene dichloride (1:3 mixture), 3 gallons; and carbon tetrachloride with chloropicrin (6:1 mixture), 12 gallons. In wooden-crib bins the dosage should be doubled. For best results these fumigants should be applied in proportionate dosages to every 1,500 bushels as the bins are filled. Paddy may also be treated in

* Their article on this subject also contains an excellent list of references.

Note: The Food and Agriculture Organization of the United Nations has published a series of papers presented at the International Meeting on Infestation of Foodstuffs, London, August 1947, under the title, *Preservation of Grains in Storage*.[74] Many of the references and quotations in this chapter are drawn from this source.

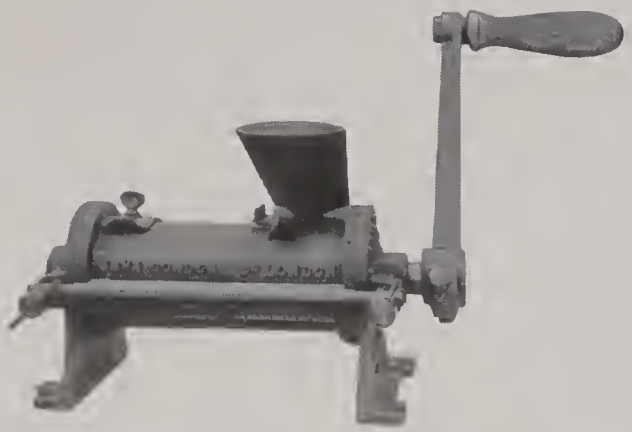
concrete elevator bins with calcium cyanide at a dosage of 15 lb. per 1,000 bushels. Milled rice in bin storage can be treated with surface applications of the fumigants at dosages recommended for treating paddy in concrete elevators."

Rice is sometimes oiled to prevent deterioration and infestation during storage. Oiling is effected in the rice-milling process by adding a very small quantity of refined white mineral oil to the rice when it passes through a slowly rotating drum set at a slight angle to the horizontal, thus assuring even distribution over the surface of each grain. The oil is tasteless and cannot be detected when the rice is eaten. Normally, only highly milled qualities of rice are oiled. In Italy, nut oil, castor oil, or vaseline is used, castor oil being the most usual. At the same time, the rice may be tinted red by the addition of an aniline dye to meet the demand in some Italian districts for a coloured rice.

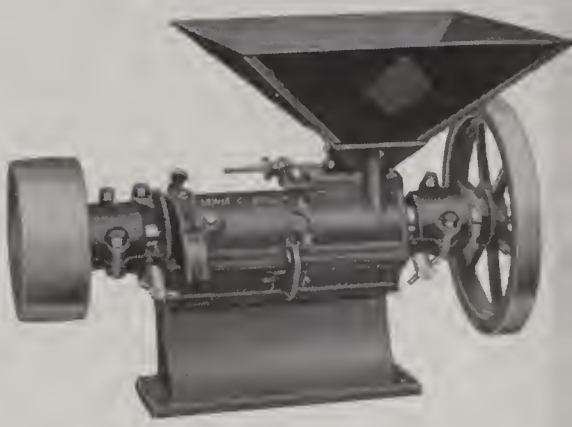
55. Husking paddy with a pestle, Bengal

56. Husking paddy, Ceylon

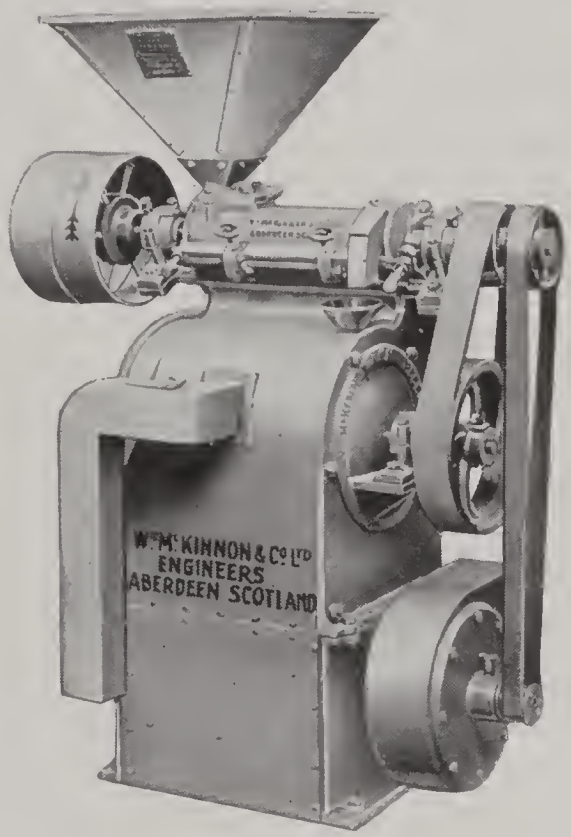
57. Milling rice, Thailand



58. Hand-operated huller
(Messrs. John Gordon & Co.)



59. Rice huller with a single pulley
(Messrs. Lewis C. Grant Ltd.)

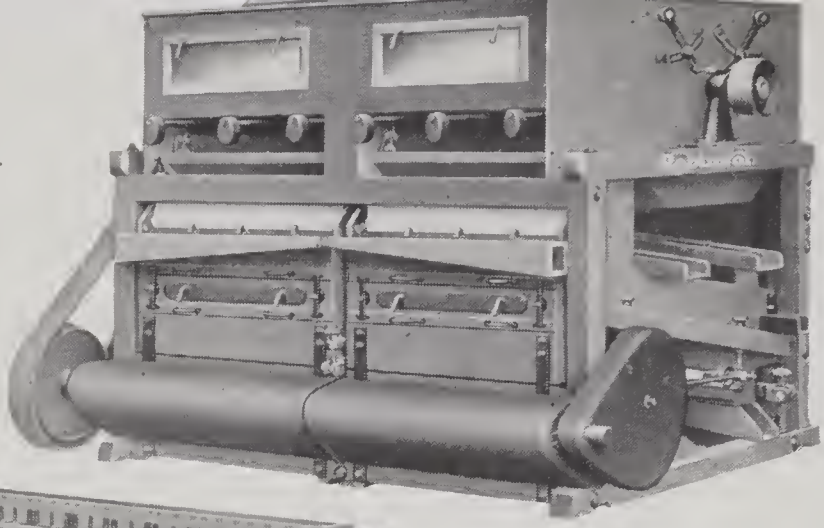


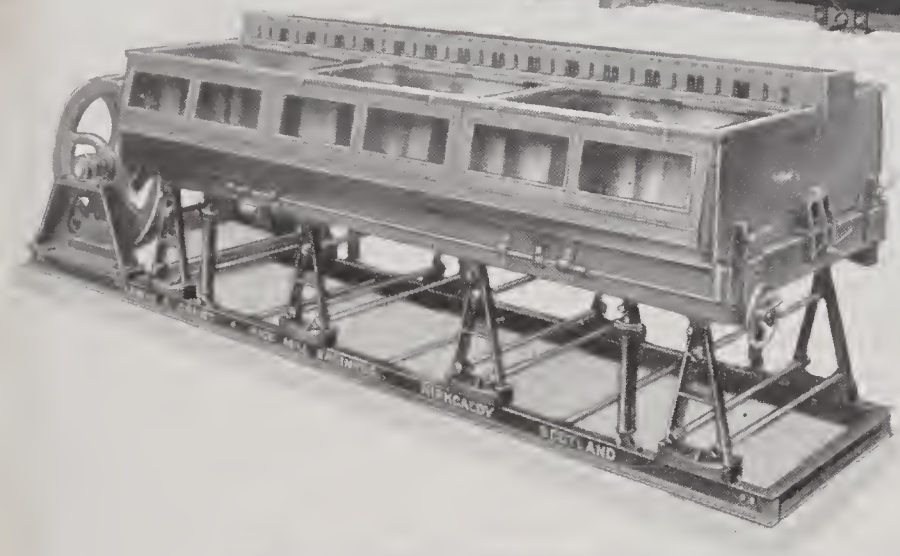
60. No. 7 Bon-Accord Combined rice Huller and Polisher
(Messrs. William McKinnon & Co. Ltd.)

61. Rice Sampling Cone
(Messrs. Lewis C. Grant Ltd.)

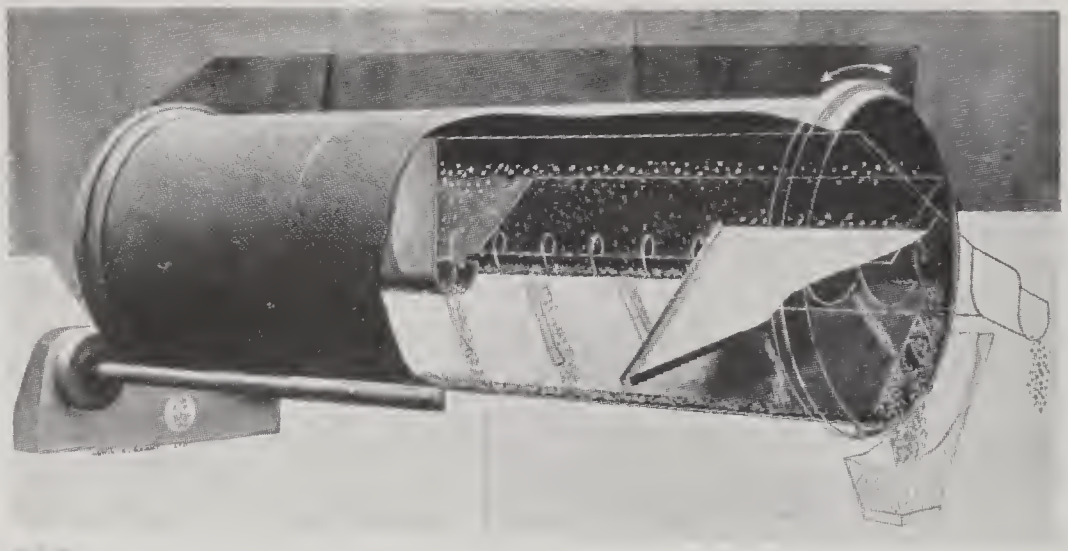
62. Hand Trieur
(Messrs. Lewis C. Grant Ltd.)

63. Ozm Paddy Intake Separator
(Messrs. Thomas Robinson & Son, Ltd.)

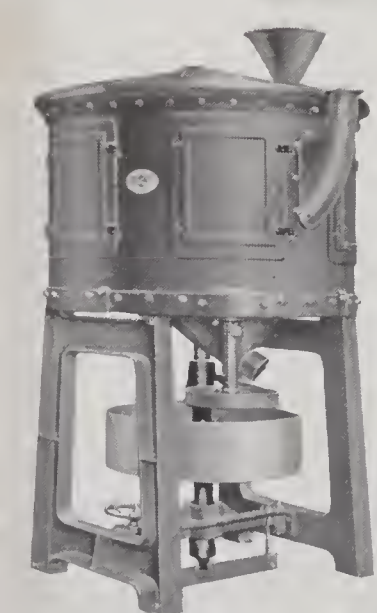




64. The Compartment Separator
(Messrs. Lewis C. Grant Ltd.)



65. High Capacity (Kapak) Separator
(Messrs. Lewis C. Grant Ltd.)



66. Pearling or Whitening Cone
(Messrs. Lewis C. Grant Ltd.)

67. Rice straw stored on a farm in the Po Valley, Italy

68. Rice straw products of Japan

Chapter XIV

MILLING

Primitive Milling Methods — Small-scale Hullers and Polishers—Milling Quality of Paddy—Large-scale Milling—Cleaning—Hulling—Milling, Pearling, or Whitening—Polishing—Grading—Electric Sorting—Summary of Milling Operations—Parboiling—Drying Paddy and Rice—Milling Products—Industrial Uses of Rice Products.

PRIMITIVE MILLING METHODS

In country districts the paddy grower sells surplus paddy, retaining sufficient for his family needs and usually a small surplus as an insurance against possible future poor harvests. The crop retained for home consumption is invariably stored in the form of paddy owing to the poorer-keeping quality of rice. The paddy is husked as it is required, so that but a few days' supply is stored in this condition.

The grain of rice is enclosed in glumes which remain in close contact with the grain. The grain has to be separated from the husk or glumes; this process is known as hulling. A variety of native implements has been devised for the purpose of hulling, the most commonly seen throughout the East being the mortar and pestle, made of wood, and worked by hand, foot, or by water power.

In the type worked by hand, the pestles are about six feet long and heavy. Usually two or three pestles are worked by a like number of people on paddy contained in one mortar. When worked by foot the pestle is on a fulcrum. The pestle is then about a foot in length and is fixed on the underside of a beam of wood. Rather more than halfway from the pestle, along the beam, is the fulcrum. A large stone may be tied on the beam above the pestle, to give added weight to the pounding of the paddy. The worker presses the beam down with the foot, thus raising the pestle; on releasing the foot the pestle falls on the paddy in the mortar. This operation is continued for some time, after which the paddy is removed from the mortar and winnowed. The portion remaining consists of rice and paddy. The operation of hulling is repeated several times until practically all the husk is removed and rice remains. Any paddy that has escaped

husking is removed by hand. Mortars are of various sizes, holding from 10 to 50 lb. paddy, and about 50 lb. paddy can be hulled in an hour.

Water power is sometimes harnessed to work a pestle, or more frequently, a battery of pestles.

Another type of huller consists of two portions of the trunk of a tree, superimposed vertically. The lower portion is solid, the top end being carved to the shape of an inverted cone. The upper contains a receptacle for paddy through the bottom of which is a hole leading to the juncture of the upper and lower portions. The underside of the top portion is smooth and conical, being made to fit into the serrated cone. The top portion also has affixed to it two handles about a foot in length.

Paddy is placed in the receptacle at the top. The worker stands facing the implement with a hand on each handle. The handles are then pushed and pulled alternately, causing the paddy which runs through the hole to be rubbed between the upper and lower portions on the serrated cone. The husk is thus separated from the grain; husk and grain is then hand-winnowed and again hulled, until freed from all husk.

There are several variations and improvements of this means of hulling paddy. In one improved type the huller, described by Jack,[122] and worked on the same principle, the lower portion is composed of unbaked clay or white ant heap tightly bound by plaited bamboo or rotan. Under the lower grinding block dried coconut fibre is tightly packed into the basket-work which is firmly pegged to the ground in a wooden frame. The object of the packing is to reduce the tendency for the clay to crack under the vibration of rotation. The basket-work of the upper mill block is continued upward to form a receptacle for the paddy to be milled. Each mill block has a grinding surface of about twenty-two inches composed of chips of hard wood, "bakau" (*Rhizophora* spp.) from one and a half to three inches wide and from one-eighth to one-quarter of an inch in thickness, sunk to a depth of four or five inches into the hardened clay. They are spaced about a quarter of an inch apart and arranged in rows running from the centre to the circumference of both grinding surfaces. The upper block is provided with a central aperture and is free to rotate on a pivot and can be adjusted to regulate the space separating it from the lower block. The pivot of the lower block is placed through the central portion of the upper block, thus keeping the upper portion in position. On the pivot rests a wooden beam embedded in the clay of the upper block and protruding through the basket-work about one foot on each side. A strong wooden rod

about four or five feet long is provided with a strong iron peg fitting loosely into a socket in the protruding end of the beam. The other end of the rod is fastened rigidly to the centre of a wooden hand-grip which is suspended about six feet above the mill.

The paddy enters the mill through the central aperture in the upper grinding surface and through the same aperture the pivot of the lower grinding block projects. The operator holds the grip with both hands and pushes it forward, causing the upper block to rotate on the stationary lower block. The rice, together with some paddy and chaff after passing between the grinding surfaces, is retained in a trough formed round the mill by the continuation of the basket-work encircling the lower grinding surface. The mixture of rice and paddy is winnowed and remilled until the rice is freed from all paddy and chaff.

The primitive methods described above are devised mainly to hull the paddy, that is, to free it from the glumes. The more it is pounded in the mortar, or ground between surfaces, the more of the germ and the epidermis of the grain is removed. This is a milling and polishing process which, with such primitive methods, is never completely effective, so that the rice still contains some of the outer coats of the grain and so, incidentally, most of the nutriment and flavour. But modern taste in rice, as in wheat, demands first and foremost appearance, so that flavour and health are sacrificed for the white appearance which can only be obtained by machines that remove these outer layers and the germ, and "polish" the rice.

SMALL-SCALE HULLERS AND POLISHERS

There are a number of hullers and polishers on the market suitable for the small-scale production of rice. They are claimed to produce a clean marketable rice of fair quality, and are suitable for smallholders, or groups of smallholders, who wish to husk and polish rice for home consumption and thus replace the ancient and slower methods of pounding the paddy. Whereas, however, the old methods resulted in an imperfectly polished rice and much of the vitamins and other nutrients were therefore retained, the amount of polishing that can be effected by the modern small-scale mill and polisher is considerable, the finished product approximating to the polished rice of commerce. Medical and other authorities have therefore urged the discouragement of these machines on the grounds that their use further increases the incidence of beri-beri and other deficiency diseases in areas and amongst a class of people at present relatively free from such ailments. The smallholder, however, will not remain

content with the antiquated and slow methods of milling. This fact must be recognized and other ways found to protect him against the ill-effects of modern milling methods.

Machines are available for hulling the paddy only or for performing the two operations of hulling and milling with the aid of a small-powered engine. Hand-operated machines are also on the market for hulling the paddy only. The operation of hulling and milling in these machines follows closely the principles of large-scale milling. Most manufacturers of rice-milling machinery produce mills for small-scale production of rice. The following are examples of such machines, but it should be understood that the writer does not thereby deny the merits of the products of other manufacturers of such mills.

As an example of a machine designed to hull paddy only may be cited Grant's Special No. 4 rice huller, which is driven by a 4 h.p. engine and has an output of 80 to 100 lb. of rice per hour from paddy. Somewhat similar hullers are manufactured by the same firm requiring from 12 to 14 b.h.p., and having an hourly output of 300 to 650 lb. rice per hour from paddy. Combined rice hullers and polishers are made in many sizes and by a number of manufacturers.

As an example of a combined rice huller and polisher may be quoted the particulars of McKinnon's No. 7 "Bon-Accord" rice huller and polisher with suction fan. It requires an engine of 9 to 12 b.h.p. to drive the belt which produces 750 to 900 revolutions per minute. It is claimed that this machine will give an output of 300 to 480 lb. of cleaned rice per hour from paddy, and is stated to be suitable for milling either raw or parboiled paddy which is free from refuse. A similar mill with a higher output and requiring greater power to drive it is also produced by the same maker. These and similar small-scale hullers and polishers are quite simple to operate and should be inexpensive to run. Spares of all parts are carried by the makers.

Hand-operated machines for the hulling of rice are suitable for use by smallholders and do not carry with them the objection of removing the nutriments from the rice. The machines manufactured in the United Kingdom are usually based on the design originated by the Engleberg Huller Company of the U.S.A., as are many of the smaller engine-powered hullers and polishers. Under the name of the original designers they are well known in the East. The small hand-powered machine in the accompanying illustration is but one example; it is inexpensive and simple in construction. One man can work the machine which, it is claimed, will treat about 40 lb. of

paddy per hour. Hand-hullers are, however, apt to be unpopular on account of their small capacity coupled with the price and the not inconsiderable effort required to work them.

MILLING QUALITY OF PADDY

The milling quality of paddy depends on the size and shape of the grain, i.e. on the variety, and on the conditions under which it was grown, the degree of ripeness, and the amount of exposure to the sun. Overripeness and excessive exposure to the sun results in the development of cracks in the grain, leading to excessive breakage in milling. Age of the grain, moisture content, and the conditions under which it has been stored also materially affect the milling quality.

In the United States the grades of paddy are determined for the Southern Rice Industry by means of the Smith Shelling device, which is officially recognized by the Department of Agriculture. The quality is determined as follows: Fifty grams of the sample are given a definite number of strokes of equal force and friction with a weighed block upon a prescribed curved surface. The surface of these two frictional elements are covered with leather, which are frequently renewed to provide a constant type of surface. The machine automatically stops after about four minutes. The sample is then removed and the whole and broken grains separated and counted. The percentage of broken grains, whole grains, and total recovery is thus determined.

A rice-sampling mill of British manufacture, which accurately reproduces the conditions of a normal cone mill, is designed to produce a sample of white rice from paddy in a few minutes. Such a machine is most useful in a rice mill to provide a quick check on the setting of cones, and is also invaluable in paddy-breeding work. Grant's Rice Sampling Cone (Plate 61) is an example of such a machine. The Minghetti Rice Testing Mill is a similar machine made in Italy. To prepare a sample, the paddy is fed into the hopper of the machine, the cone rotated for about two to four minutes according to the degree of milling required, and the sample collected from the discharge spout free from husk and bran. The machine is small and compact and requires a $\frac{1}{2}$ b.h.p. power producing a speed of 1,750 r.p.m.

To test the amount of breakage in milled rice from sheller, cone, or polisher, a hand trieur may be used (Plate 62). The Grant Sampling Hand Trieur performs this operation in two to three minutes. A measured sample of milled rice is fed into the open end of the trieur,

on which a cylinder with suitable indentations has been previously fixed. The trieur is then revolved steadily by hand for a minute or two, when the brokens are discharged on a tray, and the whole grains may be removed separately from the machine.

LARGE-SCALE MILLING

Rice mills are of various types and sizes; the larger mills may have a capacity of 200 to 500, or even 1,000 tons of paddy a day, while the small mill may be able to deal with 10 to 75 tons a day. While the former are usually situated at or near ports or in the centre of large paddy-producing areas, and are concerned with the production of rice for the export trade, the latter are usually found scattered around producing areas and mill paddy for local consumption.

The process in both large and small mills is essentially the same, although the production of rice for the export trade necessarily calls for greater care in the grading of the paddy, and in variations in milling—and particularly in the degree of milling and the proportion of broken grain in the finished rice—to conform with the requirements of importing countries than does the production of rice for local consumption. Thus, low-grade rice is the product from the same process of milling as the higher grades, except that the degree of milling and polishing is limited in the former. For the production of high-grade rice, the paddy passes through five processes in the mill, viz. cleaning, hulling, also known as shelling, pearling, polishing, and grading.

CLEANING.

Despite care in winnowing in the field or on the threshing floor, paddy as received at the mill is still in an unsuitable condition for milling, for it may contain up to 5 per cent or more of extraneous matter, such as small lumps of soil, small stones, stalk, dust, twine, nails, and other matter. It must therefore be put through a cleaning process. The machine that performs this operation may be a simple sieve riddle, a travelling flexible endless screen, or a perforated cylinder with sections of differing perforations. Usually an aspirator is fitted to the cleaning machine which removes all dust before the grain falls on the sieve. In the OZm Paddy Intake Separator, for instance, all extraneous matter larger than the paddy grain, such as straw and string, is carried away by the screen and discharged at the tail end of the machine. The sound paddy passes through the screen on to a screen which removes sand, dust, and small impurities and then flows in a thin stream into an aspirating leg, where it is sub-

jected to a current of air which carries away dead grains and any remaining dust or light impurities. Other makes of machines work on much the same principle, the basis of which is a preliminary aspiration followed by a flow over two or three screens of varying mesh, and then final aspiration.

The paddy may then be carried over a magnetic separator, which is attached to any chute or spout, and is designed to remove metal impurities in the paddy, such as nails and wire, which might injure the sheller discs of the hulling machine.

By the use of meshes of different perforations in thé cleaning machine, or by passing the paddy from the cleaning machine to a grader, the paddy may be graded as a preliminary to hulling. In this operation, the cleaned paddy passes through a revolving meshed cylinder, the thinnest grains falling through the first mesh, larger grains through succeeding meshes, the perforations of which are larger.

If the moisture content of paddy exceeds 15 per cent it is necessary to dry it before milling. Normally paddy as received at the mill in the main centres of production in Asia are sufficiently dry, but in America the use of combine harvesters results in paddy with excessive moisture content, which necessitates artificial drying before milling (see page 233).

HULLING

There are three systems of milling paddy, viz. the disc sheller, a cone mill in which an emery-surfaced truncated cone revolves within a casing of steel wire mesh; the Engleberg type of huller, which consists of a fluted cylinder running in a horizontal casing; and the Wemanco method in which the grain passes between an endless belt of rubber and an iron-grooved roll.

The essential principle of the Engleberg huller is that of a roller revolving inside a casing. Round the face of the roller are ribs, those at one end of the machine being spiral and those at the other end longitudinal. The paddy is fed into the end of the machine above the spiral ribs, and as the cylinder revolves it acts as a screw, propelling the paddy along the cylinder between the straight ribs. An adjustable blade is held in position which prevents the rice swirling round with the cylinder. In consequence of this action a mild pressure is exerted, causing the grains to rub against each other. The paddy husk, being of an abrasive nature, results in the paddy becoming shelled and ultimately whitened, and is discharged with the bran at the end of the machine. The function of the machine exerting slight pressure on the grain results in a less efficient shelling than is obtained

with the cone rice mill. In spite of its higher breakage with most rices, this system is widely employed in most modern American factories for the milling or whitening process after shelling and separation, in preference to the cone-type whitener, although the shelling or hulling may be done with disc hullers as is more usual in Asia (Fig. 30).

The cone huller or sheller consists of a rigid pan or saucer, an adjustable feed hopper, a stationary horizontal upper disc and a lower rotating disc or runner. The adjacent faces of both discs are covered with an artificial stone dressing and special emery composition* which must be kept flat and rough. The paddy is fed into a hopper at the centre of the stationary disc and is carried outwards by centrifugal force. The space between the discs is adjusted to allow the paddy to pass and in so doing the husk is removed with the minimum of damage to the rice (Fig. 27).

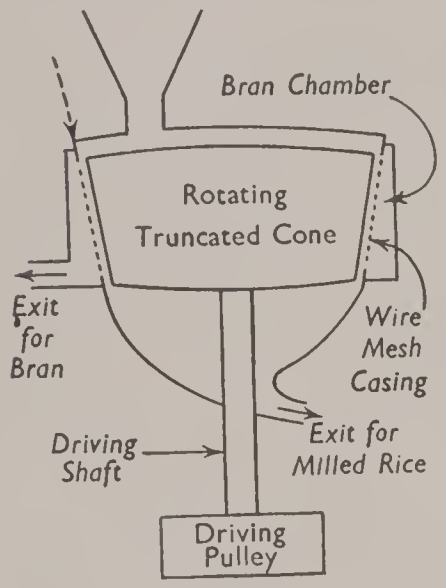


FIG. 27
Truncated-cone rice mill

The product from the huller consists of hulled grains, small paddy which has escaped hulling, husk, and broken rice. To separate these various portions the product is subjected to winnowing fans which draw off the husk and passes over sifts which remove the broken rice, known as points, and separate the bran, points and bran being discharged separately at bagging points.

The next process is to separate the paddy which has escaped the hulling process from the rice. This is done by passing the product through a special sieve and/or through a compartment separator. The principle upon which this machine works is by throwing the grains so that they impinge against a series of sharp corners, whereby the grains of greater specific gravity are impelled in one direction, while the lighter grains are driven apart in the opposite direction, the body of the machine, sliding on rockers, being driven to and fro by means of an eccentric.

The mixture of grain to be separated is fed at the top of the machine, and from thence it passes through numerous zigzag com-

* The composition is made up of emery or carborundum, a special cement, and a solution of special salts. The emery to be used depends on the particular grain, and experience of the grain to be milled is the only sure guide as to which grade of emery should be used.

partments, built at right angles to the direction in which the machine is reciprocating and sloping downwards. The paddy gradually moves up the machine to the top of the compartment and is returned to the hullers, while the rice drops to the bottom of the compartment ready for pearling. Each feed aperture can be regulated independently and the separation can be adjusted during operation by a hand wheel which causes the body of the machine to tilt its underframe. The

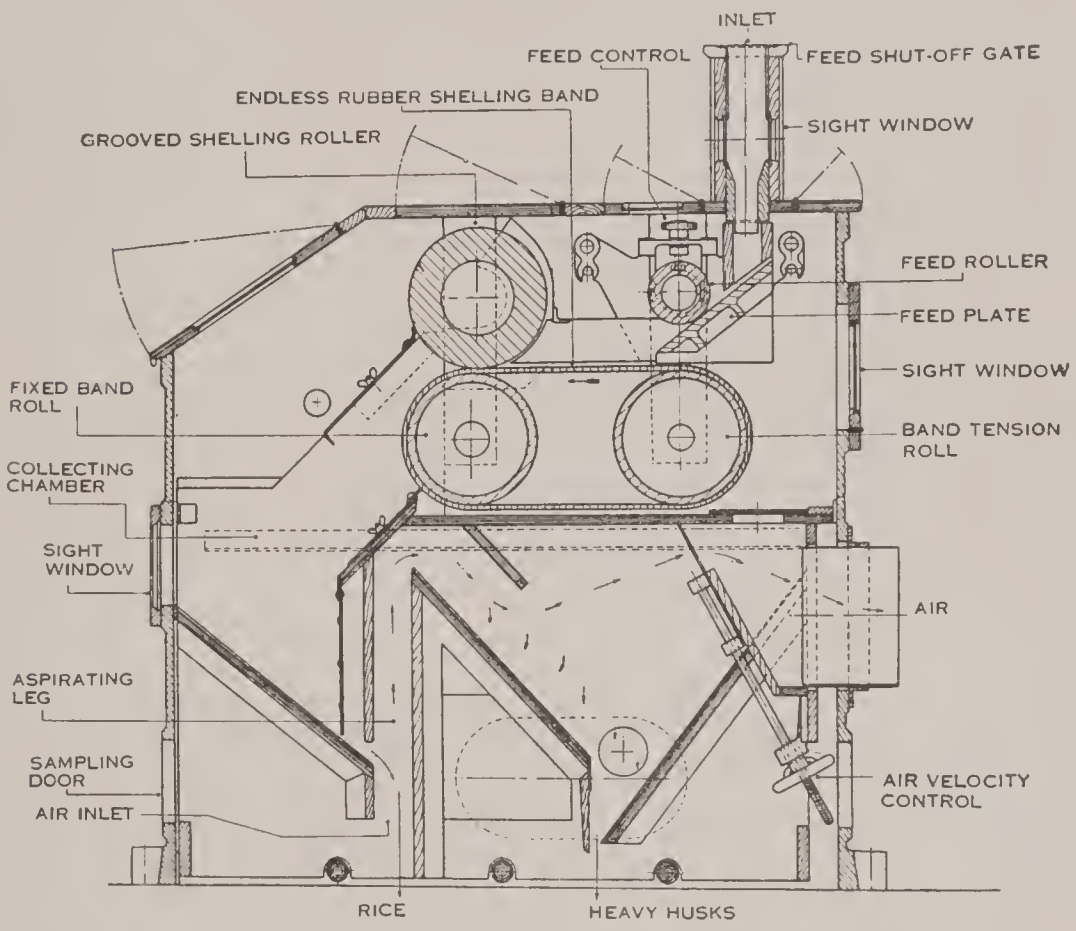


FIG. 28

Sectional drawing showing construction of the "Wemanco" rice huller (Thomas Robinson & Son, Ltd.)

shelled rice from the huller, termed *Loonzain* in Burma, is a rough rice from which the germ and most of the pericarp have not been removed.

A huller which works on a different principle from the above is the "Wemanco" Ideal Rice Huller. In this machine the shelling surfaces consist of a wide endless belt of special motor-tyre-quality rubber, precision ground to uniform thickness throughout its length and width, and a diamond-hard chilled iron-grooved roll. The rubber belt or band runs over two parallel cylindrical rolls, one of

which is fitted with special tensioned gear having an automatic compensating gear to prevent side wander, while the front or "cushion" roll over which the grain is shelled rotates in a fixed position. The fast grooved roll is mounted adjustably above the cushioning roll, with its vertical centre line slightly in advance of the latter, so that when the grain passes through the nip between the two surfaces the band is free to deflect until it reaches solid support from the roll. Both the horizontal offset and vertical clearance between shelling and cushioning rolls are independently adjustable by handwheels giving control of the pressure to which the grains are subjected so that no sound grain need be broken if correctly adjusted.

The grains travel into the shelling point on the surface of the

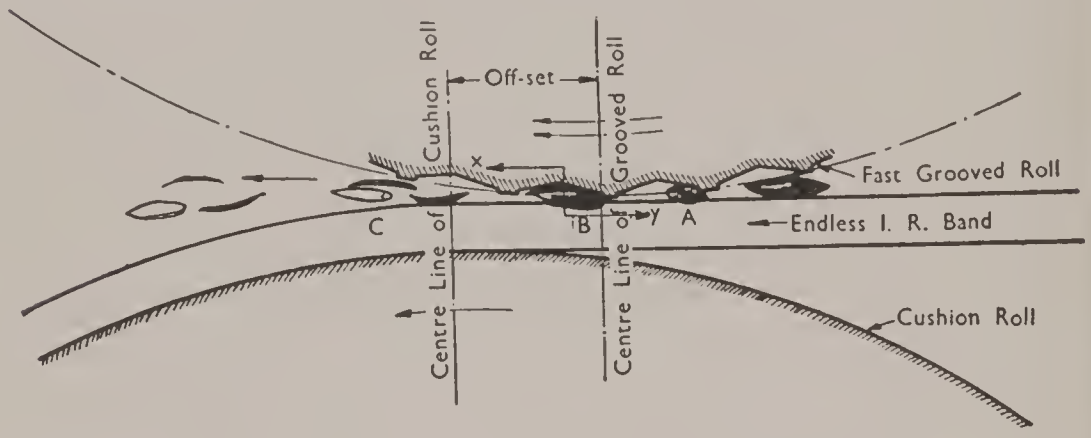


FIG. 29

Section at shelling point of the "Wemanco" rice huller
(Thomas Robinson & Son, Ltd.)

rubber band in a continuous single-layer stream across its full length. Each grain, as it reaches about the position A (see Fig. 29) is entrained in a groove of the fast roll and firmly gripped by the tooth behind, against the leading edge of which it gets firmly wedged and begins to travel at grooved-roll speed, while the lower hull surface is gently pressed into partial embedment in the resilient rubber. The band deflects easily under the grain during its travel through the ingoing side of the nip so that the pressure is light and grain slips easily over the rubber. As the grain approaches position B, the band resistance to deflection increases very rapidly and the grain becomes deeply embedded until the lower hull is momentarily held from slipping, and the leading edge of the hard grain of rice is forced through the brittle hull by the force couple x–y acting in opposite directions on either side. On reaching position C the shelled grain and hulls are then thrown off the band into a hopper. The makers claim that every mature grain is shelled whatever its size or shape,

that the ends do not get chipped, no endosperm is lost, and even the germ is preserved intact. Somewhat similar claims are, however, made for the disc sheller, but it is believed that the "Wemanco" has an advantage over the disc sheller in retaining a greater percentage of the endosperm and germ.

The mixed shelled rice and husk pass into the lower end of the vertical rising leg of the internal aspirator, up which is drawn a powerful current of air. This carries off the husk particles, and the rice falls out of the lower leg. The husk carried off in the airstream passes out of the top of the leg into a settling chamber.

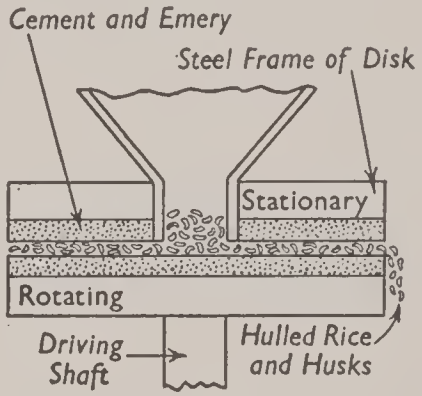


FIG. 30
Section through huller

Mortar mills were used in Italy originally, but were replaced in 1880 by a purely Italian development, the *Elichi* or *Helice*, a Screw Mortar, a development of the ancient mortar and pestle. In place of the mortar action, a worm or Archimedian screw is substituted. The shelled rice is thus agitated and by the rubbing of the grains amongst themselves, against the screws and walls of the bowl, the grains are polished.[249]

MILLING, PEARLING, OR WHITENING

The rice grain has a series of thin coats which are removed, or partly removed, when the product goes through the process of pearling, and this constitutes bran. The rice grain has, in fact, five very thin layers which together constitute the coat or cuticle, viz. the epicarp, the mesocarp, cross-layer, testa, and aleurone layer. The removal of most of these layers is effected in the process of pearling or whitening.

The Rice Pearling Cone is the standard machine for milling rice. In this machine the cuticle of the rice is removed by means of cones, usually made of cast iron and mounted on a vertical spindle taking the form of an inverted cone with the outer surface covered with an artificial dressing or emery. This cone revolves inside a casing lined with special steel wirecloth, leaving a narrow annular space surrounding the cone. The cone rotates at a high speed and rice is fed in at the top, passing down the annular space between the abrasive face and the casing. In this way the rice is "milled," that is, the waxy cuticle is scoured off. The resultant meal or "bran" is propelled through the meshes of wirecloth and is automatically collected

and delivered in bags. For milling white rice, the casing is fitted with a number of rubber brakes which are adjustable; they have the effect of increasing the milling action. Brakes are not usually used when milling parboiled rice. For white rice, the cones are worked two or three in series, or in some cases even more, according to the standard of milling required. The milling space between the cone and the casing is adjustable, so that the standard of performance can be varied by raising or lowering the cone. The closer the space between the cone and casing the higher the degree of milling and the greater the quantity of broken rice and of bran produced in relation to white rice.

The bran discharged through the wirecloth is mixed with a small quantity of broken rice known as "brokens". These are separated in bran or meal machines. The bulk of the broken rice, however, is discharged with the rice and conveyed to the polisher. At some mills in Burma, the broken rice is separated from the whole rice before being passed to the polisher, and a proportion of the broken rice is afterwards fed back to the rice according to the percentage of brokens allowed in the particular grade.

An alternative machine is the "Wemanco" Ideal Rice Whitener, by which the meal is peeled off the grain by the action of a grooved rotor, while the mass of the rice within the casing is simultaneously being subjected to vigorous intergranular rubbing under a rapid pulsating action. The endwise movement towards discharge is effected by means of inclined deflectors over the rotor. It is claimed that the rotor action effectively removes the hulls from any unshelled grains which may enter with the feed. This shelling of stray grains takes place near the head of the machine, so that neither paddy nor imperfectly milled grains find their way into the whitened product. It is claimed, therefore, that by the use of this machine paddy separators are unnecessary.

POLISHING

If a very fine appearance to the rice is desired, the rice from the pearlers is passed through one, two, or more polishers. A polisher is similar in appearance to a pearling cone except that instead of a stone- or emery-dressed cone it contains a drum covered with strips of sheep skin or buffalo hide. The rice is brushed between the skin and the casing and thus polished. The spindles can be adjusted vertically, as with the pearling cones, thus varying the space between drum and casing. A small quantity of broken rice is produced in the process, which is later separated. Where a very fine appearance

is aimed at, two or more polishers are used, and a small quantity of dry colouring matter to impart an appearance of increased whiteness may be fed with the rice in the last machine of the series.

For certain markets, notably the European and American, a rice with a fine glossy and transparent appearance is desired. This is obtained by passing the rice through glazing drums, the glazing materials—usually talc with a small quantity of very dilute glucose solution—being added with the rice to the first drum of the series of polishers.

GRADING

Rice from the polishers consists of rice and broken rice, which has now to be separated, retaining, however, a proportion of broken rice in the finished product which may vary according to the standard on which it will be sold. This separation and grading may be carried out in a series of sifts or perforated cylinders equipped with different sizes of perforations, which, stage by stage, permit the smaller sizes and grades of broken rice to pass, until finally rice containing the correct percentage of broken grain is discharged.

Another method of removing and grading broken grain is by passing the product through a series of cellular cylinders or Trieurs. The internal surface of each cylinder revolves slowly, the broken or lesser grains are caught and lifted up in these pockets and delivered by the internal mechanism to the end of the cylinder.

The "Kapak" separator is not universally used in rice mills, but is sometimes employed for special grading. It is designed to perform the same operation as the above described separators, but it does the operation more rapidly. It classifies grain according to length and can thus be used to separate broken rice from whole grains and to grade short paddy from long. On account of the internal arrangement of the machine all the grains are kept in close contact with the cylinder and thus the smaller grains are able to enter the cells more freely than in the Trieur.

ELECTRIC SORTING

Sorting machines are now on the market which make use of the photo-electric cell to remove all grain that is not white. Adjustment is possible to vary the degree of selection by colour. The capacity of such machines is at present small, they work well with "round" seed such as peas, but not with long seed as with rice. They do not appear to be a commercial proposition in the rice trade.

SUMMARY OF MILLING OPERATIONS

The paddy is poured into a hopper at the receiving end of the mill. From thence it passes either direct or by means of an elevator according to type of mill to the paddy-cleaning riddle. The cleaned paddy then passes in front of the magnet to extract any metal and is then lifted by an elevator and delivered to the sheller. The product from the sheller, consisting of shelled rice, husk, a little paddy, and some rough bran and small points, passes up an elevator to a sieve over the husk-winnowing aspirator. This sieve recovers the bran and points and discharges them to a bagging point.

The shelled rice passes up an elevator and is delivered to the pearling cone or cones. The resultant bran is automatically collected and delivered to bags and the milled rice is elevated to the polisher or polishers. Finally, the rice is elevated to the classifier. The whole rice and brokens then pass through the finishing aspirator and from thence to the bagging points.

It will be realized that a large mill may regroup machines to allow for the full working of all machines with the greatest possible continuity, minimizing handling and movement of grain from one point of the process to another. For instance, paddy graders are of various capacities up to over sixty tons per hour, the Wemanco rice huller will deal with about one ton of paddy per hour, a large pearling machine may be expected to treat about three tons of paddy an hour, and a polisher about four tons in the same period. It follows, therefore, that in a large mill there will be batteries of each machine, the number of units in each battery depending on the desired maximum output of the mill.

PARBOILING

There is a considerable demand in the East for parboiled rice. Parboiling is a process of steeping the paddy in heated water and afterwards subjecting it to steam at low pressure before drying and milling in the ordinary way. The result of parboiling is to make it easier to remove the husk, and for this reason less broken rice is obtained and the amount of milling necessary is less than for the preparation of white rice. The process as usually carried out in Asia gives the grain a yellowish colour and a distinctive flavour which render it unacceptable in many markets both in Asia and in the Western Hemisphere.

The advantages of parboiling have been summarized as follows: "Parboiling makes it possible to produce from a given amount of paddy more rice with less breakage in milling; to use a lower grade

of paddy; to obtain a rice with superior keeping qualities; and to retain more of the nutrients of the grain during milling, washing, and cooking. As a consequence, the adoption of parboiling would result in a large saving of rice and, even more important, of valuable vitamins and minerals."[211] The additional recovery of rice is considerable; from normal-grade paddy 70 per cent as against 66 per cent by milling white rice; from low-grade paddy 70 per cent as against 50 per cent by ordinary milling. In addition, parboiled rice has better keeping qualities than white rice and greater resistance to insect and fungus infestation.

In the traditional method of parboiling the paddy is steeped in

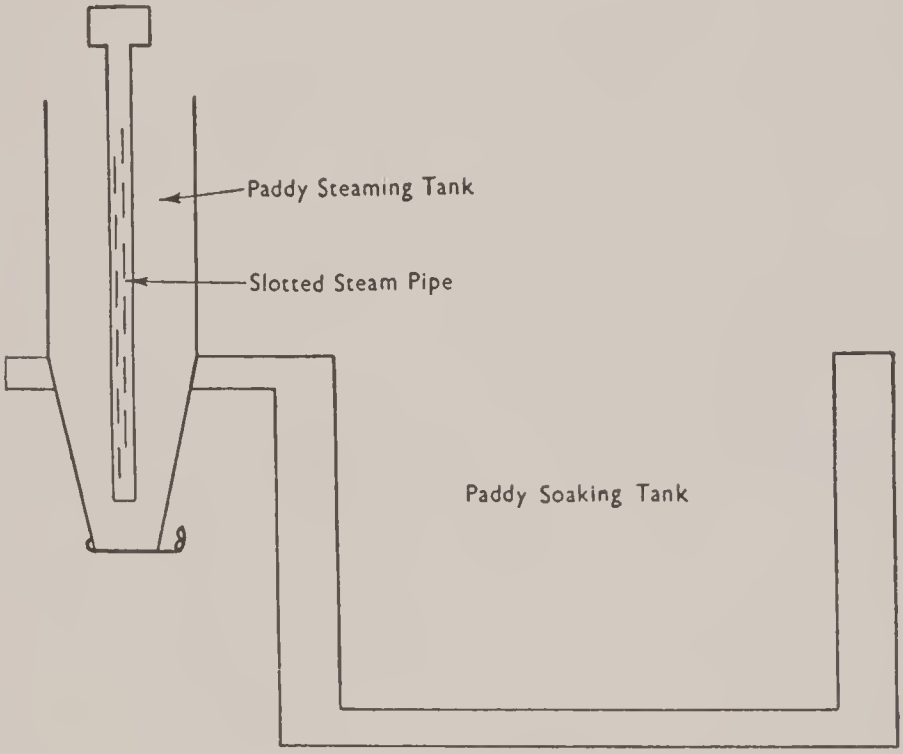


FIG. 31
Diagram of outlay for parboiling paddy

large brick tanks for a period of from one to three days, the longer period being necessary for the bolder types of paddy, which are also subjected to higher initial temperature of water. The initial temperature of water may therefore vary from 140° to 180° F. The period of steeping also varies with the season. Instead of steeping for one to three days, the paddy may be boiled for twenty minutes. It is then transferred to steel containers where it is subjected to low-pressure steam (15 lb.) for ten to twenty minutes, the bolder types of grain demanding the longer period. By this time the grain will

have become completely gelatinized. In the more modern plants the paddy is steeped and boiled in the same steel or concrete container, and by using higher average steeping-water temperatures the whole process is reduced to a period varying from eight to sixteen hours.

The paddy is then removed to drying floors, being either sun-dried or placed on steam-heated floors. The sun-dried grain is considered in Asia to be superior, for artificial drying, it is claimed, tends to give the grain a sour smell which, however, disappears when the rice is cooked for eating. It is said also to give the grain a yellow colour. More modern plants dry the grain in special drying towers, employing hot air for the purpose, and in this way eliminate the excessive labour force required by other methods. The paddy is then milled.

The desirability of replacing white by parboiled rice to effect a saving in supplies and to retain a greater proportion of the vitamins and other nutrients has led to research into modifications in the technique of parboiling to overcome the consumers' objections to parboiled rice. The following technique has been suggested[211] to achieve this object: cleaning the paddy by blowing and washing, soaking at 25° to 30° C. for one day, changing the water several times during soaking; steaming in autoclave at 120° C. for fifteen minutes and drying by a counter-current of hot air. The same authority claims that improvement in the parboiling technique is both desirable and possible by simple modifications of the present methods and suggests: careful cleaning of the paddy; in cleaning the water must be changed several times, the temperature should not be too high, but sufficiently high to shorten the soaking time to about twelve hours; heating by live steam for thirty minutes. Atmospheric pressure appears to produce less colouration of the grain; drying at too high a temperature should be avoided to prevent colouration of the grain.

Improvements were made in the method of parboiling in British Guiana[199] by speeding up the operation as a result of steeping the paddy in water kept in constant circulation at a temperature of about 160° F., thereby reducing the soaking by about four hours. Thereafter, the paddy is steamed for about ten minutes only. By this method it is claimed that there is no fermentation with resultant odour, and a greatly improved product is obtained.

According to Subrahmanyan and his co-workers parboiled rice can be almost as white and palatable as polished rice—colour and flavour depending largely on the technique of parboiling. They state that the colour depends to some extent on the colour of the

husk and also on the methods used in parboiling. Charlton[44] also showed that much of the objectionable flavour and odour is due to incorrect methods of preliminary soaking which encourage the development of fermentation due to anaerobic bacteria.

Parboiled rice when cooked for eating has better keeping qualities than has ordinary white rice and does not so readily turn sour. Simpson[236] assumes that the keeping qualities of parboiled rice are considerably superior to those of undermilled rice, even if they are not so good as polished rice, due to the fact that the process of parboiling removes the greater part of the oil in the grain. Furthermore, the steaming process, he states, is likely to sterilize the grain and thus destroy enzymes and moulds which might subsequently damage the grain. He adds that "provided the final drying of the grain is sufficient, there appears to be no reason why parboiled rice should not be capable of storage for considerable periods without undue deterioration."

DRYING PADDY AND RICE

To obtain the best milling results the moisture content of paddy should not exceed 14 per cent. Little difficulty is usually experienced by millers in the East to ensure that the paddy is sufficiently dry. The grain is usually spread on a concrete floor in the open, where a few hours' exposure to the sun is sufficient to ensure dryness. Rice after parboiling is usually dried in the same way, although artificial drying is now largely replacing sun-drying of parboiled rice. The serious disadvantage of sun-drying of paddy is that it cracks the grain, resulting in a high percentage of breakage in milling. In America, where the crop is reaped by combine harvesters, the moisture content of the paddy is usually over 20 per cent, and artificial drying is essential.

The paddy drier is a tower provided with a series of louvres. The top portion preheats the paddy before subjecting it to the drying medium. The air is drawn in by a fan and heated before being introduced to the tower. The air temperature and therefore the temperature to which the paddy is heated is controlled thermostatically.

The damp paddy is fed by means of a hopper at the top of the drier, from where it flows by gravity over the louvres to the exit at the bottom of the tower. The passage of the paddy down the tower is automatically regulated to the amount of feed.

Parboiled paddy leaves the boiling pans at a high temperature so that no preheating before drying is necessary. The preheater sec-

tion of the column is therefore dispensed with and the whole column is employed for drying, for which one heater and one fan are sufficient to supply the hot air.

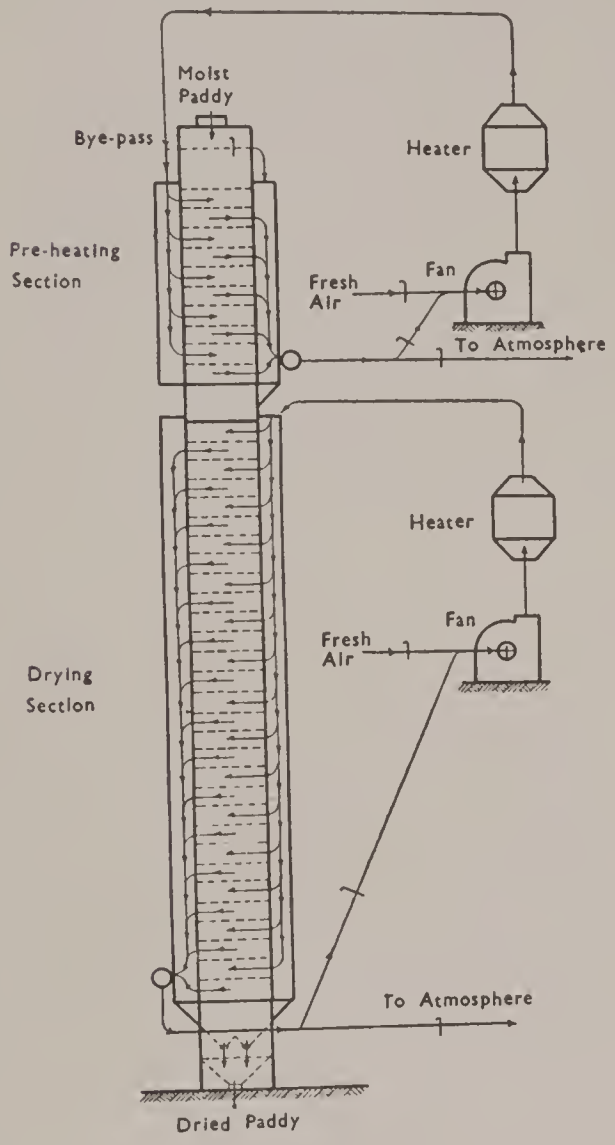


FIG. 32
Diagrammatic arrangement of paddy drier (Thomas Robinson & Son, Ltd.)

Steam is the usual medium for the hot air, the air being drawn in by a fan and heated by radiator-type heaters. Paddy husk is usually employed as fuel for the furnace.

In British Guiana[199] it was found essential before drying that the paddy should be thoroughly cleaned to enable the grain to travel smoothly through the drier, and it was necessary to remove shelled grain, otherwise, after parboiling, such grain became shapeless and gummy and gummed up elevators, conveyors, and driers. To effect this cleaning, a Scalperator, a Monitor, and a Carter Disc Separator were installed ahead of the soaking tanks. Furthermore, it was found necessary to dry parboiled paddy to at least 13 per cent, otherwise the paddy gummed up the hullers and the brush. Drying problems were eventually solved by drying to 18 per cent moisture content in a Robinson drier and then passing the paddy on to a Hess drier for the extraction of the remaining moisture.

MILLING PRODUCTS

The weight of husk is about 20 per cent of the weight of the paddy. In addition there may be about 5 per cent of dirt, dead grain, and other extraneous matter in the paddy, so that the miller may expect to obtain about 75 per cent of the paddy in rice and its by-products. In milling and polishing rice the following percentage products are

therefore obtained: Rice 48, points and broken rice 16, bran 13, meal 3, husk 20. These figures will vary according to the variety of rice, its age and moisture content, and on the degree of milling and polishing.

In many countries of production steps have been taken by governments to control the milling rate in order to increase rice supplies. Many of the existing mills in Asia are, however, said to be either worn out or outmoded and are therefore incapable of being adjusted for undermilling to any appreciable extent. On the average, the rates of conversion of paddy to rice approximate 70 per cent in Asia and 65 per cent in non-Asiatic countries.

Burma has for long been the most important exporter of rice. In that country there are over 800 mills, most of which are small, for the bulk of the milling is done in a few large mills in Lower Burma. Consequent on its world trade, very numerous grades of milled rice are exported to satisfy the particular requirements of each market. These grades depend on several factors, in particular, the variety or type of paddy from which it is milled, the degree of milling, and the percentage of broken grain. Similarly, but to a less degree, grades are recognized for rice obtained from other centres of production.

Broken Grain

The amount of broken grain resulting from the milling of rice depends mainly on the variety of paddy, its condition—especially its degree of dryness—and the amount of milling to which it is subjected. Several grades of broken rice are recognized in the trade, grade depending largely on the grades of milled rice from which it was obtained. In Italy[249] brokens are made into rice flour, sometimes mixed with wheat flour to make "bread of real luxury with a most agreeable taste."

Rice Meal and Rice Bran

Two kinds of bran are obtained from the milling process. Cowbran is produced in the hulling of paddy. It is a coarse meal of low food value. The bran or meal produced in the pearling process comprises the pericarp, the aleurone layer and the embryo of the grain, and some of the endosperm, and contains most of the vitamins and proteins of the grain. It has, therefore, a high food value and commands a ready market. Burma recognizes two main grades, No. 1 Bran or White Meal, produced from white rice milling, and No. 2 Brown Bran, produced from the milling of parboiled rice.

The composition of rice meal varies widely according to the quality of the paddy and the method of milling. Analyses of Italian meals gave the following figures:[258]

Albuminoids	..	11·25 to 13·37 per cent
Fats ..	..	10·63 to 14·80 „ „
Carbohydrates	..	39·82 to 43·01 „ „

The digestibility was over 75 per cent, and the meal is in Italy considered a perfect and agreeable food for milch cattle.

A fat, known as "rice oil," is extracted from rice meal in Italy, either by mechanical means or by solvents. The pressed oil is greenish and deposits stearin. It is used in soap-making, but not as an edible oil as it turns rancid very quickly. If the oil is left in the bran it is apt to make the bran rancid and so spoil it as a cattle food. It is, in fact, better to feed bran from which the oil has been extracted by solvents, because the treatment kills the enzymes which otherwise are liable to produce irritant and purgative substances.[35]

INDUSTRIAL USES OF RICE PRODUCTS

Rice is mainly used as a food, being boiled or steamed and eaten with meats, fish, and vegetables. It has also many other uses in food and commerce. In 1930 it was estimated, for instance, that 86·5 per cent of Japanese production of rice was used as food, 5·2 per cent for making wines, 4·9 per cent for cakes, 1·2 per cent for seed, 1·1 per cent for sugar, and smaller amounts for salted bean paste, soya sauce and vinegar, and for starch. The following notes[35] indicate some of these uses of rice.

Starch

Rice with the minimum of proteins is required for starch manufacture. Highly polished rice—whether it is much broken does not matter—is therefore largely used. Over-boiled rice is used in Asia for starching clothes. Rice is employed as a material in the European starch industry, and also to some extent in Asia. Rice powder is used in Asia as a cosmetic.

Beverages

Various alcoholic beverages are manufactured from rice, the Japanese national drink *Saki* being the best known of these, and the most perfected process so far evolved in this direction. For the manufacture of alcohol from starch the Asiatic employs cultures of certain fungi which convert starch into dextrose, and these being associated with yeast, lead to the production of alcohol. An established trade in these cultures is familiar throughout the East. They are made up in the form of small, generally flat cakes in India, China, Japan, Indo-China, and Java to inoculate fermentable liquids and turn

them into beers, wines, and other alcoholic drinks. Very old, dry, and finely ground rice is used as a base, to which is mixed various strong-smelling substances, mostly spices, the main fuction of which is probably to assist the acids which the fungi produce in suppressing bacteria, supply a little food to the fungi and yeasts, and encourage changes which alter the flavour. The mixture is worked up moist and infected with the fungus and the yeasts from old stock, lightly covered or shaded and kept in a cool place. In a few days the fungus sends its hyphae through the cakes; the cakes are then dried, the fungus and yeasts in them having passed into a resting stage. The fungi present depend on the origin of the preparation; the Japanese form contains *Aspergillus oryzae*, elsewhere species of *Mucor* are present and seem to be the most important. A common genus is *Rhizopus* and there are others. The fungus turns the starch of the grain into glucose; the yeasts then convert the glucose into alcohol—the first is an aerobic process, the second anaerobic. Pure cultures of the Chinese *Mucor* (*Chlamydomucor*) and the yeasts can be purchased for obtaining alcohol from rice for the manufacture of pale beers.

For making rice beer, the rice is boiled, spread out, and inoculated with one of the above-mentioned "cakes," which are sprinkled over it. It is then wrapped in fresh leaves and kept moist, when a slightly alcoholic, sweet fluid with a sweet-sour taste exudes, which must be consumed within a few days as it will not keep. It is frequently used for yeast in cake-making, while the slightly fermented rice is used in food.

Rice wine is made from glutinous rice, which is boiled and inoculated with fungi and yeast "cake" and left for a prolonged period in open tubs, then decanted into closed vessels which are then buried for several months.

In the manufacture of rice-spirit, or arak, the Chinese boil cargo rice until it is soft, when with the addition of water it is inoculated. The brew is allowed to stand for twenty-seven days and is then distilled. The process in a Chinese distillery in Indo-China is said to consist in boiling and inoculating rice and allowing the mash to ferment one day in open vessels and then for a week in closed vessels, by which time the process is complete.

Rice in Medicines and Magic

As is to be expected, the use of rice in various forms as a medicine is general throughout Asia; likewise its employment in magic and in religious ceremonies is but natural when one remembers how closely this cereal has entered into everyday life of the Asiatic

through countless centuries. These subjects are, however, beyond the scope of the present book.

Rice Husk

The husk is valueless as a food and is used as fuel for the engines supplying the power in rice mills. According to the *Manchester Guardian* of 11th December 1931, however, a soap powder has been made from this material, and it is stated that a company was planning to engage in the manufacture of rice soap on a large scale. Rice husks are frequently employed in the East, especially in Japan, as a packing material for fragile china. It is stated that charred husk has been used in New Orleans as a substitute for bone-black in refining sugar, while in the Philippines a distillate from the incomplete combustion of the husks is known as a home medicine.

Rice Straw

Rice straw is used for the manufacture of strawboards. In Japan it is used for braiding, and imported rice-straw is employed in hat-making in the Philippines. It is also used for mat-making, and in China for mushroom cultivation. Lye from burned straw ash with other substances is used in Java for washing the hair, and if taken internally, is regarded as an abortifacient.

The average food content of dry straw, according to Tognato,[258] is albuminoids 3·7 per cent, fats 1·42 per cent, carbohydrates 32·33 per cent. He discusses the use of rice straw in the feeding of cattle. The digestibility of the straw is inferior to that of other cereal straws, but this authority states that experience has shown that mixed with potatoes, beet, or beet juice, or other concentrates, it can be fed to milch cows and to bullocks in quantities up to half the total daily food. Ensilage of rice straw is also possible. The straw is stacked in the open and covered with stones or earth to create a pressure of about 100 lb. per square foot for several months. The straw assumes a brown colour and pleasant odour and is readily consumed by cattle. The percentage analysis is: albuminoids 4·8, fats 2·2, non-nitrogenous extracts 25·6.

Chapter XV

THE NUTRITIONAL VALUE OF RICE

Quality and Quantity—Nutrients in Rice—Minerals—Vitamins—Effect of Milling on Nutritive Value—Losses in Washing, Cooking, and Storage—Effect of Parboiling—Deficiencies of Rice Diets—Deficiency Diseases—Undermilling Processes—Parboiling Processes—Artificially Enriched Rice—Development and Application of New Processes—Summary—Acknowledgement.

QUALITY AND QUANTITY

THE rice-eating Asiatic subsists almost entirely on rice, consequently the nutritive value of this cereal is of the utmost importance to a very large section of the inhabitants of the Eastern Hemisphere. The problem confronting the dietician is a twofold one: to supply a diet that has the highest possible food value, and to supply it in sufficient quantity; it is a simple question of quality and quantity. It is an established fact that millions of Asiatics live on an insufficient quantity of food, many on the verge of starvation; there are also many others—not necessarily the poorest—who suffer from the effects of an unbalanced diet of which rice forms the major part. Among the rice-eating people the general level of health is low in comparison with Western standards, resulting in high mortality rates, short expectation of life, the prevalence of disease, and poor physical development and working capacity.

One effect of the poor nutritive value of the diet is the incidence of the disease beri-beri, and also a number of deficiency diseases less spectacular than beri-beri but none the less insidious in undermining the health of vast populations.

Rice is not a complete food, so that even should the present shortage of rice supplies give place to an abundance of this cereal, the nutritional problem will remain, and only by improving the standard of diet by the consumption of greater quantities of other desirable foods can any material improvement in the health of Asiatic rice-eaters be assured. This aspect of the subject, however, is outside the scope of the present book. Apart from such considera-

tions, an improvement in the quality of the rice consumed would go far towards eliminating some of the worst and widespread of the deficiency diseases, and would therefore raise the general health standard amongst these people.

NUTRIENTS IN RICE

The composition of rice differs with the variety. It is also said to vary according to the soil in which it is grown and with manuring. Information on these points is at present very incomplete; while analyses of a number of varieties show variation, little work has been done towards correlating nutrient content with improved varieties, while the information on the effect of cultivation and manuring on nutrient content of the grain is still inconclusive. In any case, the losses of nutrients in milling, storage, and cooking so far outweigh in importance any advantage that might accrue by increasing the nutrients in the varieties as to render this line of approach relatively unimportant.

The composition of rice, according to three authorities, is shown in Table 8.

TABLE 8*

COMPOSITION OF RICE—HUSKED AND POLISHED
(Percentage, on moisture-free basis)

	Husked			*Milled*			*Losses on milling and polishing*		
	Platt	*Kik and Williams*	*Rosedale*	*Platt*	*Kik and Williams*	*Rosedale*	*Platt*	*Kik and Williams*	*Rosedale*
Fat	2·45	2·2	2·23	0·37	0·34	0·4	84·9	84·6	86·5
Crude fibre ..	0·88	1·1	0·6	0·16	0·23	0·4	81·8	79·1	33·3
Ash	1·22	2·09	1·19	0·36	0·45	0·9	70·5	78·5	24·1
Protein ..	8·67	9·78	9·54	8·15	8·64	6·7	6·0	11·4	29·4
Carbohydrates	86·67	84·83	86·34	90·79	90·33	91·4	-4·7	-6·5	-5·5

The fat content of rice is low and much of the fat is lost in the process of milling. The protein content of milled rice is low in comparison with other cereals, although the whole grain contains about the same quantity as is found in wheat. It compares favourably with other cereals in the amino-acid content, and the digestibility of the

* References in Bibliography

proteins is high, being 96·5 for the whole grain and 98 per cent for milled rice. The low content of lysine is the most serious amino-acid deficiency. Rosedale[220] gives the following amino-acid analysis of the protein of rice: (in percentages) Ammonia 6·5, Humin nitrogen 5·2, Total bases nitrogen 27·3, Arginine N. 13·7, Histidine N. 0·9, Lysine N. 8·9, Mono-amino N. 43·7, Cystine N. 1·1, Tryptophan N. 0·9.

MINERALS

The comparison of the mineral composition of husked and polished rice is given in Table 9. A normal diet, concludes Rosedale, of husked rice will supply about half the requirement of iodine and the required amount of lime. The human nutritional requirement of iron is estimated to be about 10 to 15 ~~micro~~milligrams daily—husked rice will supply about 19 ~~micro~~milligrams and polished rice not more than 6 ~~micro~~milligrams. The calcium/phosphorus ratio is unfavourable, being about 1 : 10 instead of 1 : 2 which is regarded as the optimum ratio.

TABLE 9

MINERAL CONTENT OF HUSKED AND POLISHED RICE
(percentage)

	Husked	*Polished*
Chlorine (Cl) ..	0·2863	0·048
Phosphorus (P_2O_5)	0·393	0·380
Calcium (CaO) ..	0·0927	0·014
Magnesium (MgO)	0·0778	0·036
Sodium (Na) ..	0·0542	0·022
Potash (K_2O) ..	0·1421	0·074
Sulphur (SO_4) ..	0·0024	0·0038
Iron (Fe)	0·003177	0·00102
Copper (Cu) ..	2·3 in 100 gm.	1·3 in 100 gm.
Manganese (Mn)	15·7 ,, ,, ,,	13·8 ,, ,, ,,
Iodine (I)	3·88 ,, ,, ,,	2·6 ,, ,, ,,

micrograms per 100 gms.

VITAMINS

The amount of fat-soluble vitamins A and D in rice are negligible, but the vitamin E content of whole rice is considerable. Husked rice has a high content of vitamin B, at least one-tenth that of dried yeast. The riboflavin content is low and vitamin C practically absent. The average amounts of vitamins of the B complex, particularly Ethiamine (B1), riboflavin, and niacin are of the order 4 micrograms*

* Approximately 3 micrograms per gram equals 1 International unit.

of thiamine, 0·6 micrograms riboflavin, and 50 micrograms of niacin per gram. Kik[135] has shown that the content of thiamine and riboflavin is influenced by geographical location: for instance, the variety Nira showed 4·63 u.g./gm. of thiamine in Arkansas, 4·74 in Louisiana, 3·3 in Texas, and 5·05 in California. Niacin, however, appears to be little affected by locality. Further, Kik found that thiamine, riboflavin, and niacin content differs between varieties. Rice is a good source of pantothenic acid and pyridoxine, two other vitamins of the B complex.

The early workers, realizing that high milling of rice resulted in the incidence of beri-beri, assumed that the thiamine content of the rice is mainly present in the aleurone layer and the embryo of the rice grain. However, Altson and Simpson[5] in 1941, by dissecting the grain, showed that about 50 per cent of the thiamine content is concentrated in the embryo. It followed, therefore, that to preserve the thiamine the retention of the pericarp was of secondary importance to the embryo. Continuation of their research work was interrupted by the war in Malaya, and it was Hinton[107] who, in England, investigated the distribution of vitamin B_1 in wheat and other cereals and in 1948 extended his investigations to both red and white rice. His results for white rice, dehusked by hand, are given in Table 10.

TABLE 10

VITAMIN B_1 CONTENT OF FRACTIONS OF THE RICE GRAIN

Part of grain	*Proportion of grain* (%)	*Vitamin B_1 content* (*i.u./g.*)	*Equivalent vitamin B_1 in whole grain* (*i.u./100 g.*)	*Proportion of the total vitamin B_1 of the grain* (%)
Pericarp aleurone ..	5·95	10·5	62·5	35·2
Covering to germ ..	0·20	4·0	0·8	
Epiblast	0·27	26·0	7·02	3·9
Coleorhiza	0·2	31·5	6·3	3·5
Plumule	0·31	15·5	4·8	2·7
Radicle	0·17	21·5	3·65	2·0
Scutellum	1·25	63·0	78·8	43·9
Outer endosperm ..	18·8	0·45	8·46	8·8
Inner endosperm ..	73·1	0·1	7·31	
Total			179·64	
Vitamin B_1 actually found in whole ..			186·0	

The results show that, as with other grains, there is a high concentration of vitamin B_1 in the scutellum (44 per cent), while the aleurone

layer contains 35 per cent, the embryo 12·3 per cent, and the endosperm 8·8 per cent. There appears to be a normal tendency, states Hinton, for vitamin B_1 to be concentrated in young leaves still in the process of differentiation, and as explaining the high concentration of B_1 in the scutellum and aleurone layer it is pointed out that the former is regarded as a modified leaf and becomes, as it were, fixed in a stage of partial differentiation and may therefore partake of this tendency to concentrate vitamin B_1.

The distribution of vitamin B_1 in red rice was found to be: scutellum 50 per cent, aleurone layer 33 per cent, embryo 9·7 per cent, and the endosperm 6·3 per cent of the total vitamin B_1.

In view of these conclusions it follows that milling should be designed to remove the pericarp, but to retain the scutellum and as much of the aleurone layer as possible.

EFFECT OF MILLING ON NUTRITIVE VALUE

The losses of nutrients resulting from the milling and polishing of rice are very considerable. The degree of milling and polishing determines the amount of nutrients removed. Proteins, fats, vitamins, and minerals are present in greater quantities in the germ and outer layers than in the starchy endosperm. The removal of the protecting pericarp also facilitates the extraction of soluble substances from the aleurone layers during washing immediately before cooking the grain. The pericarp, however, is fibrous and also contains much phytin, which forms insoluble compounds with calcium and iron and may, therefore, immobilize these elements from absorption during digestion. Rosedale shows that the losses on polishing are 29 per cent of the protein, 79 per cent of the fat, 84 per cent of the lime, and 67 per cent of the iron. He continues: "The difference in protein content between the two rices which is about 2 grams per 100 grams may not at first sight appear to be large, but a calculation shows that it may be very important. A man who eats 21·4 oz. (2,200 calories) of husked rice would get 53 grams of protein, whereas by eating a similar quantity of polished rice he would get only 38 grams of protein. This really constitutes the difference between a minimum protein requirement and a sub-minimal amount or shortage of protein if he eats polished rice. The League of Nations Technical Commission recommended 1 gm. of protein per kg. of body weight as satisfying requirements. Oliveiro[175] showed that normally nourished people weighed 58·1 kg. Thus, 53 gms. of protein goes far in securing the protein requirement."

Rosedale further points out that the husked rice has a high content

of vitamin B while polished rice has little or none, and that the iodine value of polished rice is 11·5 as compared with 43·6 per cent in husked rice and 85·16 per cent in rice polishings. A normal diet of husked rice will supply about half the requirements of iodine and the required amount of lime. Reference to the above table also shows that nearly all the unsaturated fatty acids in rice are lost in polishing, and as Rosedale remarks: "this may well be serious in a diet, such as is taken by the average rice-eater, which is usually so high in its content of carbohydrates."

The losses of nutrients due to milling and polishing are stated in Table 8. Such variations as are there shown in the figures of different authorities doubtless reflect conditions of environment under which the rice was grown, different varieties, and varying degrees of milling.

Kik and Williams[134] state that the average thiamine, riboflavin, and niacin content of thirteen varieties of husked rice were 3·55, 0·6, and 53·08 micrograms/grams, while the corresponding figures for milled rice were 0·8, 0·26, and 19·62 micrograms/grams. In addition, therefore, to the loss of protein and fat, and of valuable minerals, the milling and polishing of rice results in losses of 76 per cent of the thiamine, 56 per cent of the riboflavin, and 63 per cent of the niacin.

LOSSES IN WASHING, COOKING, AND STORAGE

It is customary to wash rice, often with several changes of water, before cooking to remove dust, insects, husks, and other impurities. The amount of washing considered necessary depends on the condition of the rice, badly stored rice containing a large amount of broken rice, and dirty rice demanding more attention than does a fine sample of highly milled and well-stored rice.

The effect of washing rice is to dissolve some of the nutrients from the grain, the amount removed depending on the degree of milling and the amount of washing.

Methods of cooking vary in different countries. The four main methods are:[284]

(1) Large amounts of water are used and the excess drained away, carrying with it much starch which has been rendered soluble.

(2) The rinsed raw rice is immersed in water just sufficient to swell the grains properly, and cooked in a double boiler or over a slow fire to avoid charring at the bottom, until the water is fully absorbed.

(3) Rinsing the cooked rice. This is often done to ensure the

complete removal of the films of soluble starch on the surface of the grains.

(4) Rice is sometimes half-cooked by boiling, after which the water is drained off and the rice steamed to a state of tenderness in a pan or basket in an enclosed space over freely boiling water.

Habitual rice-eaters affirm that there is no one way to cook rice; certain varieties of rice and rice grown in certain localities require different treatment in cooking.

The use of excess water causes the most depletion of vitamins. The excess washing of the uncooked rice and the discarding of the cooking water result in a very serious loss of calories and nutrients. The losses resulting from the washing and cooking methods commonly used in India were calories 15 per cent, proteins 10 per cent, iron 75 per cent, calcium and phosphorus 50 per cent.[195] The washing of milled rice may result in the loss of 40 per cent of the thiamine, 25 per cent of the riboflavin, and 23 per cent of the niacin.

The cooking of rice in a double boiler results in a small loss of vitamins and other nutrients, but large losses are inseparable from cooking in open vessels. As will be seen below, better retention of vitamins results from cooking, by whatever method, rice enriched according to recently introduced methods.

The loss of nutrients as a result of faulty storage is self-evident. Spoilage of grain by insects and moulds may be reduced to a minimum by ensuring that the rice is sufficiently dry before storage. Husked and undermilled rice which is thoroughly dry and kept in properly constructed and ventilated stores will remain undamaged for considerable periods, although it is more liable to attack than are milled rice and paddy. The admixture of lime to milled rice improves the keeping quality provided the mixture is stored in a thoroughly dry condition.

The prolonged storage of rice under bad conditions affects cooking quality also, probably as a result of changes in the starch fraction. Loss of vitamins appears to be inseparable with storage under normal conditions. Kik[135] shows that whereas cold storage for two and a half years did not cause any significant loss of vitamins, the average percentage losses in the whole kernels kept at room temperature for the same period were 24·9 thiamine, 5·3 riboflavin, and 3·9 niacin.

EFFECT OF PARBOILING

The method of parboiling rice is described in Chapter XIV. In this process paddy is soaked in water for three or four days, after

which it is steamed for a short period. This parboiled paddy is then dried, hulled, and pearled.

The process of parboiling toughens the grain and reduces the amount of breakage in milling. The milled product is less liable to insect attack and has better keeping qualities than milled raw rice. In parboiling some of the vitamins are driven into the endosperm and by gelatinizing the starch of the outer layers seals the aleurone layer and the scutellum, so that they are not readily removed in milling. Milled parboiled rice contains two to four times as much thiamine and niacin as milled raw rice and rather more riboflavin (Table 11).

TABLE 11

VITAMIN CONTENT OF HUSKED AND PARBOILED RICE
(percentage)

Variety	*Thiamine* (mg.)		*Riboflavin* (mg.)		*Niacin* (mg.)	
	Milled parboiled	*Milled raw*	*Milled parboiled*	*Milled raw*	*Milled parboiled*	*Milled raw*
Nira ..	1·35	0·59	0·47	0·30	49·0	20·6
Coloro	1·61	0·84	0·33	0·26	45·2	18·5

Washing affects the water-soluble vitamin content of parboiled rice much less than it affects that of raw rice. Swaminathan[248] has shown that whereas raw milled rice loses about 77 per cent of its thiamine in washing and cooking, the loss from parboiled rice similarly treated is only about 36 per cent. After washing, parboiled rice may contain four times as much thiamine and niacin as washed raw rice. The explanation appears to be that the penetration of the water-soluble vitamins into the endosperm during steaming makes them less "accessible" to water used in washing.

Hinton[108] demonstrates that parboiling or conversion treatment (which is in fact a parboiling process) leads to the redistribution of vitamin B_1 in the grain, with the result that the endosperm is considerably enriched. He suggests that the redistribution is mainly due to the entry into the grain, as the starch gelatinizes, of a small amount of water condensed on its surface. He found that a proportion, varying according to the conditions of treatment, was not redistributed but lost. This was mainly an effect of the steaming treatment to which the scutellum appeared to be more sensitive than the embryo.

Hinton also confirms that there is a marked retention of the

scutellum in milled parboiled rice as compared with milled raw rice. "How far the retention of the germ is responsible for the higher vitamin B_1 content of the rice milled after parboiling is not clear, but the fact that the germ is not so readily dislodged from parboiled grain does indicate the need for experiment on how far the type or severity of the milling process and the detailed conditions of pre-treatment influence the quality of the final product."

DEFICIENCIES OF RICE DIETS

It has been shown above that rice is subjected to a series of conditions and treatments from the time it is harvested to the time it is consumed which seriously depletes it of its nutrients—the protein, fats, and carbohydrates; the minerals; the vitamins. The rice-eater, whose health depends on the quantity and quality of the rice he eats, consumes a product of satisfactory appearance from which most of the nutrients have been removed. Some of the losses of nutrients are inevitable; milling is essential, but faulty milling, due frequently to the employment of mills in need of repair and replacements, results in a high percentage of "breakage," and consequent loss of vitamins. Washing and cooking are essential, but the supply of rice relatively free of impurities would necessitate less vigorous and extensive washing and a consequent saving of calories and nutrients; cooking is essential, and here well-directed propaganda is desirable to ensure that the rice is cooked in the minimum quantity of water in order to conserve the nutrients. "The drastic washing of rice and the discarding of the cooking water will nullify any improvements in the nutritive value of the rice previous to household preparation."[265]

The most important deficiency of typical rice diets is in the B group of vitamins and of vitamin A and calcium. It is suggested[205] that the thiamine content of milled rice should be 1·8 micrograms per gram to ensure that the rice as consumed will not be dangerously poor in this important vitamin. Further, it is considered that a greater intake is desirable of protein derived from food other than rice. The amount of fat eaten in rice-consuming countries is low, and in view of the fact that fat facilitates the absorption of certain vitamins and "spares" thiamine, an increase in consumption of fat is desirable.

DEFICIENCY DISEASES

Deficiency diseases may be caused by an insufficient intake of food, by deficiencies in the quality of the food eaten, or by an ill-balanced diet.

Beri-beri is the best known of the deficiency diseases caused by rice. Rare before the introduction of the truncated-cone type of rice mill, it has since become prevalent throughout the rice-eating regions of Asia. While the cause of the disease has for long been known and its prevention and cure is simple and well understood, the beri-beri problem remains unsolved. It is stated, for instance, that in the Philippines, of a total population of 14 million in 1946, the deaths by beri-beri were 18,582 infants and 4,567 adults. The problem remains unsolved because prejudice and inertia dictate that it shall be so. Lord Dunsany recounts[72] how, speaking at King's College, London, he referred to the folly of polishing rice till all the nutriment was extracted from it, and quoted from *The Times* an account of a journey in tropical Asia when the porters died one by one, not from the rigours of nature, but from beri-beri. "One student, an Indian," he adds, "asked me, when I had finished, if I knew that unpolished rice was brown and dirty. I asked him if he knew what beri-beri was, and received the astonishing answer: 'Certainly I do. Many members of my family suffered from it.' "

The irony of the situation is that the beri-beri patients are cured by giving them the very vitamins they have discarded from their rice.

Over sixty years ago Admiral Takaki eliminated beri-beri from the Japanese navy by partially replacing milled rice in the diet by barley and wheat. In 1910 undermilled rice was given to the Philippine Scouts instead of polished rice, when the incidence of beri-beri fell from 10 to 1 per cent within a year; and beri-beri disappeared from Javanese prisons when husked rice was introduced.

Eykman and Gryns in Java from 1890 to 1900 established the fact that beri-beri is a food deficiency associated with the consumption of milled rice and stated that it could be prevented by replacing milled rice by husked rice or undermilled rice. It was further observed that beri-beri was rare in areas where home-pounded rice was eaten. This last observation, however, may be partly explained, as is pointed out by Simpson,[236] by the fact that the diet of those who pound their own rice is supplemented to a considerable extent by green vegetables and other sources of vitamin B_1. The present writer has observed that green vegetables as consumed by villagers who pound their own rice are usually very lightly cooked, so that the retention of vitamins is considerable. Dr. Braddon, working among Indians who eat parboiled rice and Chinese labourers who eat polished rice, observed the important fact that eaters of parboiled rice rarely contract beri-beri.[31] The antineuritic value of parboiled rice has since been demonstrated by many authorities.

Research has clearly demonstrated the anti-beri-beri properties of

undermilled rice. The consumption of rice not deprived of its outer layers will prevent the disease, while a diet including the "polishings" obtained in the process of removing the outer layers of the rice will effect a cure of the disease provided it is not in a too advanced stage. "The disease in its acute form often leads to the sudden death of breast-fed infants during the second to the fourth month of life. If recognized it can be effectively treated by the timely injection of thiamine and the recovery of an infant within twelve to twenty-four hours after the injection of a few milligrams of thiamine can be very dramatic."[284]

But beri-beri is not, unfortunately, the only deficiency disease associated with polished rice. Keratomalacia, stomatitis, glossitis, cheilosis, "burning feet," and heptic cirrhosis occur most frequently amongst rice-eaters, states *Rice and Rice Diets*,[284] while, the same authority adds, experience in prison camps in the East during the war proved that neurological manifestations were associated with deficiency of factors in the B complex of vitamins. "Burning feet," retrobulbar neuritis, spinal ataxia, spastic ataxia, and simple spastic paraplegia were among the conditions observed. The authority for the above statement concludes that "further research on this subject —which is greatly needed—is likely to provide more evidence of the ill-effects of malnutrition on the human organism and to show that deficiency states which are still relatively unfamiliar are exceptionally prevalent among rice-eating populations."

Prejudice and inertia are difficult to overcome—and are by no means confined to Asia (cf. the prejudice in the Western Hemisphere against bread that is not white). But whereas the varied diet in the West compensates for deficiencies of any particular food, the great dependence in the East on rice as the mainstay of the diet emphasizes the necessity of ensuring that the quality of this cereal as consumed should be of a high order. While international and intergovernmental action is designed to insist on the degree of milling in conformity with a high nutritional quality in the milled product, it is unlikely that such action alone will go far enough to overcome the present dangers associated with overmilled rice.

Hitherto, governmental action has been directed to the undermilling of rice to prevent undue loss of vitamins and other nutrients. The two main objections to this policy are: firstly, the prejudice of rice-eaters against undermilled rice, and secondly, the fact that undermilled rice has poorer keeping qualities than highly polished rice. Recent developments designed to ensure the high quality of rice have been directed to the improvement of the present process of milling; or alternatively, to enriching by artificial means highly

polished rice to the level of the original or unpolished or husked rice.

The methods of improving the nutritional value of rice which are available for commercial application include two milling processes, viz. the Earle Process and the Wemanco Process; two developments of the parboiling process, viz. the H.R. Conversion Process and the Malek Process; and two methods of artificially enriching rice, viz. the Hoffman-La Roche Method and the Fieger Method.

UNDERMILLING PROCESSES

Earle-processed Rice

The Earle process aims at the retention of much of the vitamins by undermilling the rice by a new patented process. In this, the paddy is fed into a tubular mill, the inner lining of which is of $\frac{1}{4}$-inch thick rubber. Inside the mill are placed several loose rubber-covered steel rods of two-inch diameter. These rods rotate in different directions and at different speeds, both in relation to themselves and to the mill shell. The rods do not cascade, as the motion is entirely one of rubbing. As the peeled rice comes from the mill, the bran and trash are eliminated by means of blowers.

By this process it is claimed that breakage of grain is reduced and nutrients are retained. Whereas in the ordinary milling of rice about 8 per cent of bran is obtained, in the Earle process only about 1 per cent is obtained.

Kik[135] observes that Earle-processed rice may be susceptible to the attack of weevils and to rancidity in storage due to the presence of fat in the retained bran layers. The amount of vitamins retained depends on the amount of peeling; removing 0·57 per cent of the bran, 61 per cent of the thiamine, 54 per cent of the riboflavin, and 63 per cent of the niacin were retained.

The Wemanco Process of hulling and whitening rice has been described in Chapter XIV. The claims for the process are that it has not only simplified milling, but that the percentage of broken grain is much reduced, due to the low rotor surface speed; the particular advantage claimed for the process is the high nutritional value of the white rice produced by the retention in the grain of the thiamine. This is said to be due to the action of the revolving rotor used, which rapidly removes the bran without the scutellum being knocked out. Analyses of white rice milled direct from shelled rice in the Wemanco whiteners show a vitamin retention comparable to that of parboiled rice milled by ordinary methods.

The main differences between the action of milling by the Wemanco and the disc huller are that the latter shells the grains while on end

while the former shells on the flat, and the Wemanco whitens the rice by peeling plus intergranular rubbing, while the cone whitens by abrasion plus intergranular rubbing.

PARBOILING PROCESSES

The F.A.O. International Rice Commission appear to favour developments in the parboiling process as a means of increasing output and improved quality. In a recent report they state:[211] "Parboiling makes it possible to produce from a given amount of paddy more rice with less breakage in milling; to use a lower grade of paddy; to obtain a rice with superior keeping qualities; and to retain more of the nutrients of the grain during milling, washing, and cooking. As a consequence, the adoption of parboiling would result in a large saving of rice and, even more important, of valuable vitamins and minerals." Changes in technique have been suggested to assist in overcoming some of the disadvantages of parboiling, information on which is given in Chapter XIV. In addition, two patented processes have been developed to effect improvements, viz. the H.R. Conversion Process and the Malek Process.

The H.R. Conversion Process

Under this process the paddy is cleaned in the usual way, followed by the removal of light grains, hulls, and other light matter through flotation. This is effected by placing the paddy in a trough of turbulent water, the light matter rising to the surface and being floated off, while the heavier grain is removed from the bottom of the trough by an enclosed screw conveyor.

The wet paddy is then placed in a large vessel which is evacuated (to twenty-five inches or more) for at least ten minutes. Hot water (75 to 85° C.) is then introduced under a pressure of 80 to 100 lb. per square inch and the paddy steeped under these conditions, with recirculation of the water for a given time, varying from 120 to 165 minutes, depending on the variety of paddy, moisture content, the length of time it has been in storage, and on the colour desired in the final product. The steeping water is then drawn off and the paddy introduced into a cylindrical, rotating, steam-jacketed vessel, which is then partially evacuated. At this point steam is introduced and the paddy heated for a short time. The steam is then blown off and a vacuum of twenty-eight to twenty-nine inches applied. The product is thus dried under vacuum in the rotating steam-jacketed vessel until the moisture content is rather less than 15 per cent. It is possible to air-dry the product without damage to the milling quality provided that the grain temperature never exceeds 145° C.

The hot, dry, "converted" paddy is then placed in bins and cooled by passing air through it; it is allowed to remain for at least eight hours in the bins before milling; this "tempering" period is considered necessary to ensure a state of moisture equilibrium throughout the mass. The paddy is then milled in the usual way. A smaller amount of bran is obtained than is usual in milling unconverted paddy, and a very small amount of polish is obtained—suggesting undermilling.

The finished product is said to have a yellow colour, but comparison with white rice in the cooked state shows only a barely discernible yellow colour. The grain is said to be more resistant to insect attack than untreated rice. This process is being operated commercially in the United States.

The average retention of vitamins in converted rice is stated to be 92·25 per cent of the thiamine, 70·82 per cent of the riboflavin, and 77·62 per cent of the niacin in the original rice.

Malekized Rice

Malekized rice is the product of another patented process of parboiling paddy. The paddy is soaked in water at 100° F. for four to six hours, then steamed for about fifteen minutes at 15 lb. pressure, dried, and milled in the usual manner.

The finished product is either packed in bulk or is boiled and canned in vacuum-sealed tins, being sold as canned-Malek cooked rice. The cooked rice in the cans is absolutely sterile. Kik[135] gives the following figures for vitamins in bulked Malekized rice, in micrograms per gram: thiamine 2·0, riboflavin 0·4, niacin 44·0. The canned product showed 0·6, 0·3, and 30·0 micrograms per gram respectively.

Artificially Enriched Rice

Two methods of artificially enriching rice that have been developed are based on the restoration of nutrients to the level found in husked, unpolished rice. In both the enrichment is carried out in two steps: (*a*) producing a fortified premix, and (*b*) mixing or diluting the premix with ordinary white rice during the usual polishing process.

The Fieger Method

In this method the polished rice is impregnated with a water solution of thiamine, niacin, and a highly soluble salt—sodium phosphate. The treated rice contains a high concentration of vitamins and is intimately mixed with untreated rice at the ratio of 1 : 100. After drying, the impregnated rice is coated with a thin collodion

membrane so that while the vitamins are protected from loss during the washing of the rice, they are available in the cooked rice, since the film is removed by hot water.

By this method of enriching rice, the loss of thiamine in washing was reduced to 13·5 per cent, and the loss during cooking in a double boiler 6·4 per cent; when cooked in an open vessel it was 49·1 per cent. In washing, 14·1 per cent of the niacin was also lost.

The Hoffman-La Roche Method

In this method developed by Hoffman-La Roche Inc. of New Jersey, white rice is impregnated with a concentrated solution of the vitamins, followed by coating the fortified rice with film-forming

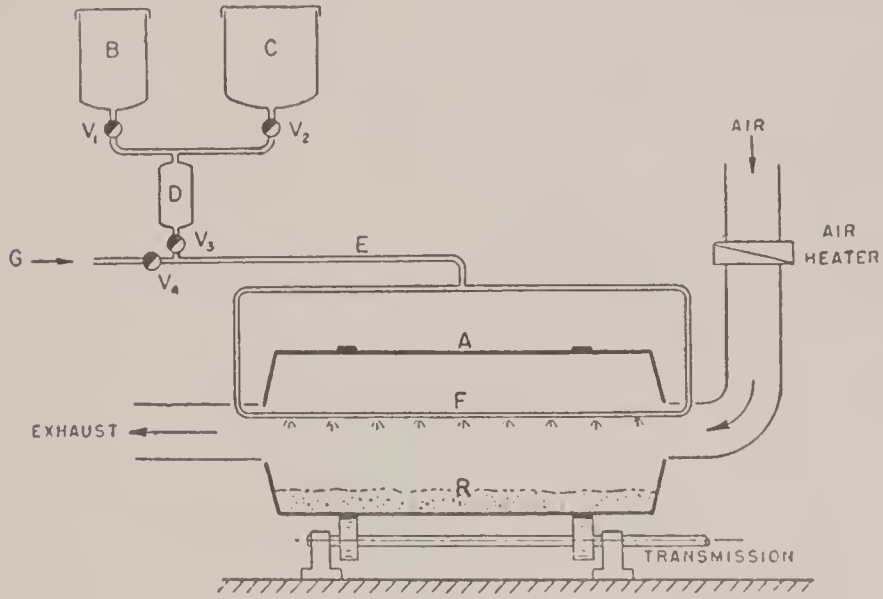


Fig. 33

Diagram of Roche pilot plant for production of rice premix

edible substances, designed to protect the vitamins against deterioration and to prevent any substantial loss of vitamins during the washing of the grain before cooking.

The operation of this process has been described as follows:[81] White rice is introduced through a hopper into a motor-driven trumbol A—a rotary device used for coating or mixing rice after polishing. The trumbol is rotated at a fixed rate while the vitamin solution from a kettle B is allowed to flow through the measuring cylinder D and into the trumbol via a distributor pipe E, which slowly sprays the solution over the rotating rice grains through the perforated section F. After the final portion of the vitamin solution is blown out of the sprinkler pipe with compressed air from G, the blower is started to draw preheated air through the rotating trumbol

until the rice is thoroughly dry. Half the coating solution in kettle C is measured into the system through D and sprayed over the rotating rice through F. After thorough coating has been achieved and the major part of the solvent evaporated, an iron pyrophosphate mixture is added by a scoop which slides in F. A second coating of protective solution is then applied and dried as before. The finished premix is removed from the trumbol through discharge slots and screened to remove "agglomerates" which form to the extent of about 1 per cent of the rice during processing. Enriched rice is prepared by mixing premix and white rice in the ratio of 1 : 200, either in the trumbol or in any other suitable mixer. On a commercial scale the mixing can be carried out conveniently during the coating of the white rice.

The blending of the premix with white rice during the polishing process in the rice mill results in a product in which—if thiamine and niacin are used—neither the premix nor the enriched rice differs in appearance from ordinary polished white rice; the addition of riboflavin, however, changes the colour of the premix sufficiently to make it visible in the blend.

Fortification of the premix with 1 mg. thiamine and 13 mg. niacin per one gram of premix and a ratio of 1 : 200 premix to white rice restores approximately the vitamin content to the standard of brown quality rice. Enriched rice prepared on this basis contains 5 mg. thiamine and 65 mg. niacin per kg. (2·27 mg. thiamine and 29·5 mg. niacin per lb.). The cost of the two vitamins, the cooking ingredients, the manufacture of the premix, and the blending is estimated not to exceed 0·114 cents (gold) per lb. of the enriched rice, or $0·25 per person per annum.

The premix is homogeneously distributed throughout the finished enriched rice, and the usual washing of the rice before cooking will not remove more than 1 or 2 per cent of the added vitamins. It is claimed that the flavour and cooking quality are not affected by this fortification process. Furthermore, it is stated that storage for a year at room temperature does not affect the thiamine or niacin incorporated. When stored for three weeks at a temperature of 45° C. a loss of 3 per cent of thiamine resulted, but there was no loss of niacin. Loss of vitamins by washing the rice before cooking was 7·9 per cent of the thiamine, 3·45 per cent of the riboflavin, and 9·09 per cent of the niacin. When cooked in an open vessel, 14·33 per cent of the thiamine and 11·15 per cent of the riboflavin was lost; using the double boiler 3·12 per cent of the thiamine and 2·68 per cent of the riboflavin was lost.

DEVELOPMENT AND APPLICATION OF NEW PROCESSES

The methods of preparing rice detailed above variously aim at preventing loss in bulk in milling, retaining or improving the quantity of nutrients, particularly vitamins, in the finished product, and protecting these nutrients against loss in storage, preparation for cooking, and in cooking. Considerable strides towards the achievement of these objects are evident, while the palatability of the treated product has not been found to be impaired to any great extent.

The adoption of improvements on a large scale, however, presents difficulties. Rice which is different in appearance from ordinary rice will meet with disfavour. The prejudice of rice-eaters to a rice having a different flavour or appearance from what they are accustomed, unfortunately is very real, but it should not prove impossible to overcome provided the difference is not too pronounced; meanwhile it would appear advisable to avoid as far as possible giving the consumer grounds for complaint. Another difficulty in putting into effect a large-scale programme of rice vitaminization is the provision of capital and operational costs. The problem is surely a national one, and its solution must rest with the governments of countries concerned with this problem of malnutrition. The present loss through disease, lowered vitality, and premature death as well as the widespread misery caused by malnutrition throughout Asia, is so immense, and the cost of maintaining medical and other services so great, that one is prompted to conclude that no price is likely to be too high to overcome these conditions. Purely on a basis of economics it must surely pay to develop an ambitious scheme that would ensure the advantages of enriched rice to the peoples of Asia —and one cannot believe that the cost would be so prohibitive as not to be borne, at least in part, by the consumers themselves.

The choice of method to be adopted to ensure that the population is supplied with a rice diet rich in vitamins will depend upon local circumstances, such as the present preferences of the population, the size of the population, and the available capital for the project. For instance, for a population accustomed to eating parboiled rice, one of the improved parboiling processes might be indicated, whereas a population demanding a highly polished rice of high quality would take more kindly to an enriched rice. Further, a combination of undermilling with enrichment might be considered in certain cases.

It is understood[219] that in consequence of a decrease in beri-beri of 72 per cent amongst the population in the Bataan area of the Philip-

pines fed on a vitamin-enriched rice, the government of that country is extending the use of enriched rice to three additional provinces with a total population of 1,800,000 people. It is recorded that consumers have not objected to the enriched rice, on the contrary they prefer it to the normal.

The preliminary investigations which led the Philippine government to undertake this project are of great interest, and the outcome of this ambitious scheme will undoubtedly exert a profound influence and serve to stimulate action in other countries in Asia where the problem of malnutrition is no less evident than in the Philippines.

SUMMARY

Possibly over 600 million people in Asia derive 50 per cent or more of their food calories from rice, and the majority exist at a low level of consumption of calories per capita. There is abundant evidence that this undernourishment has seriously affected their health, pointing to the urgent necessity of a close examination of the subject with the object of devising methods of improvement in the diets. A Nutrition Committee was convened in accordance with the recommendations of the Rice Study Group of the Food and Agriculture Organization of the United Nations in 1947 to consider nutrition problems in the East, with special reference to rice. In a recent report,[205] this Committee stated that effective regional nutrition programmes "should be concerned with the elimination of waste at all stages between production and consumption; the improvement of the nutrient content of rice by better milling practices; the extended use of parboiled rice and the introduction of enriched rice; and the improvement of rice diets by suitable supplements and substitutes for rice."

The need for action is evident and the lines upon which such action should be taken are defined. Further research will doubtless suggest means for further improvements. It is therefore to be hoped that well co-ordinated action at national and international levels will be taken to improve the diets and the health of the numerous rice-eating nations in Asia.

ACKNOWLEDGEMENT

Details of most of the new processes described above are freely drawn from Bulletin No. 458 of the University of Arkansas, by M. C. Kik, and many of the vitamin analyses quoted are from the

same source. Articles on the Nutritional Improvement of Rice by A. Sreenivasan,[241] and Rice and its Nutritional Aspects, by L. Nicholls[171] have also been consulted in the preparation of this chapter. Other sources of information are indicated by bibliographical references in the text.

Chapter XVI

PRODUCTION, YIELDS, AND CONSUMPTION

Importance of Rice in Asia—Areas of Production—World Production of Rice—Yields—Possibility of Increasing Yields —The Effect of Climate on Yields—Consumption—The Post-war Position—Prices—Government Intervention inthe Rice Industry.

IMPORTANCE OF RICE IN ASIA

Rice has been the means of enabling the populations of Asia to survive, inasmuch as wet rice more than any other cereal crop helps to check erosion. It is certain that had the people of Asia attempted to live by any other cereal they could not possibly have maintained their population density as they have done for thousands of years. Growing wet paddy necessitates water conservation and this in turn automatically ensures soil conservation. Some of the terraced fields in Indonesia, the Philippines, and south China are over two thousand years old, and they are typically conservation projects. This more than any other factor accounts for the predominance of rice as the staple food in south-east Asia, in countries of high rainfall.

Rice remains the most important food of countless millions of people in Asia, and among the poor of these nations it is practically their only food. The very poor, if they live outside a rice-producing region, may not be able to afford rice and will subsist on other grains or pulses; ragi (*Eleusine coracana*), for instance, is the main diet in certain parts of India, but once a ragi eater becomes accustomed to rice it is with the greatest reluctance that he will return to eating ragi.

The fact that rice is the staple food of the great majority of the people of Asia makes it of vital importance to the economy of the countries concerned. In the extensive rice-producing areas practically the entire population is either directly or indirectly dependent on the success of the crop, a dependence that extends beyond the growers to the commercial community, for ability to buy depends on the proceeds of the rice harvest.

Outside the rice-producing areas, the influence of rice on the economic life of the communities and the countries may be more

subtle but is just as important as in them. Inability to buy rice freely through interruption of normal imports causes disruption of labour conditions which may affect countries outside the region directly concerned.

Wages are largely ruled by the price at which the workers can buy rice; if supplies are short, causing a rise in price, and almost invariably the creation of a black market, increases in wages are demanded and are difficult to resist, resulting in an all-round increase not only in the cost of living, but in the cost of production of export goods upon which the country may be dependent.

The important place which rice takes in the agriculture of many countries in Asia is succinctly stated by Wickizer and Bennett[271] in the following table showing the rice acreage as a percentage of the total crop-producing area:

Indo-China	86	Java	45
Burma	65	Chosen	30
Philippines	64	India	23
Formosa	54	China	21
Japan	45		

AREAS OF PRODUCTION

Excluding the U.S.S.R., from which no information is available, the total world area under paddy in the season before the outbreak of the war in 1939 was between 200 and 203 million acres. Post-war efforts to step up production to meet increased demands have led to an increase in area of approximately 9 million acres. Shortage of supplies during the war provided an incentive to increased production in Africa and the Western Hemisphere, but despite this, 90 per cent of the area under this crop is still to be found in Asia. In south-east Asia—the traditional home of the crop—and in eastern Asia vast areas of low land have for centuries produced an annual crop of rice, while smaller areas follow the course of rivers far inland; the crop also extends up the steep sides of hills that, with infinite care and skill, past generations of paddy-planters have terraced and irrigated to provide conditions suitable for their staple food crop.

The most important regions of rice production are China and India, which together account for over 50 per cent of the world total area under the crop.

In Asia in the thirty years before the Second World War the area planted remained static in the countries of greatest importance, with the possible exception of Indonesia, where the area increased from

about 5½ million acres in 1912 to over 9 million acres in 1939, an increase due entirely to the vigorous policy of the Dutch government, which was determined to make the territory self-sufficient in the crop upon which the well-being of the population depended. The Indian acreage also showed an apparent increase during the same period; this may in some measure be due to improved statistics, but in any case it was nullified by the very considerable increase in the local population. The total increase in area in the eleven most important Asiatic countries of production between the years 1920 and 1939 was in the region of 15½ million acres, representing an annual increase of 0·6 per cent.

In Japan[139] there has been a gradual increase in area, production, and yield per unit area during the past sixty years. This is attributable mainly to the increased use of fertilizers and to the planting of improved varieties, while the decrease in yield during the past five years is stated to be due to difficulty in obtaining adequate supplies of fertilizers.

In many parts of Asia there was necessarily a set-back to planting during the war from 1939 to 1946. Recovery, due largely to the dire necessity of the planters themselves, has been rapid in some countries, but slow in others where the present political unrest militates against full recovery, especially in the countries that normally have a large exportable surplus.

The Colombo Plan[204] stresses the present poverty of the people, focuses attention on the needs and difficulties of south and south-east Asia, and envisages a six-year plan for economic development of the Commonwealth countries in this area. Agriculture, and in particular rice cultivation, figures prominently in this plan, for the central problem here is still the supply of food for the increasing population. If the present rates of increase are maintained the present population of about 570 million will, before 1970, have increased to 720 million. In India, new irrigation works, some of which are already in hand, are designed to develop 6 million acres of potentially good agricultural land from which 3 million tons of food grains as well as other products will, it is hoped, be obtained. In Pakistan, an additional half a million tons of rice are expected as a result of new irrigation works and drainage measures, whereby some 6 million acres will benefit. By 1957 Ceylon expects an increase of about ¼ million acres under food crops which should produce 75,000 tons of rice annually. Malaya contemplates measures to increase rice production, but anticipates that this increase will do little more than keep pace with the rapidly increasing population. When the various programmes are completed, states the Report, 13 million acres more

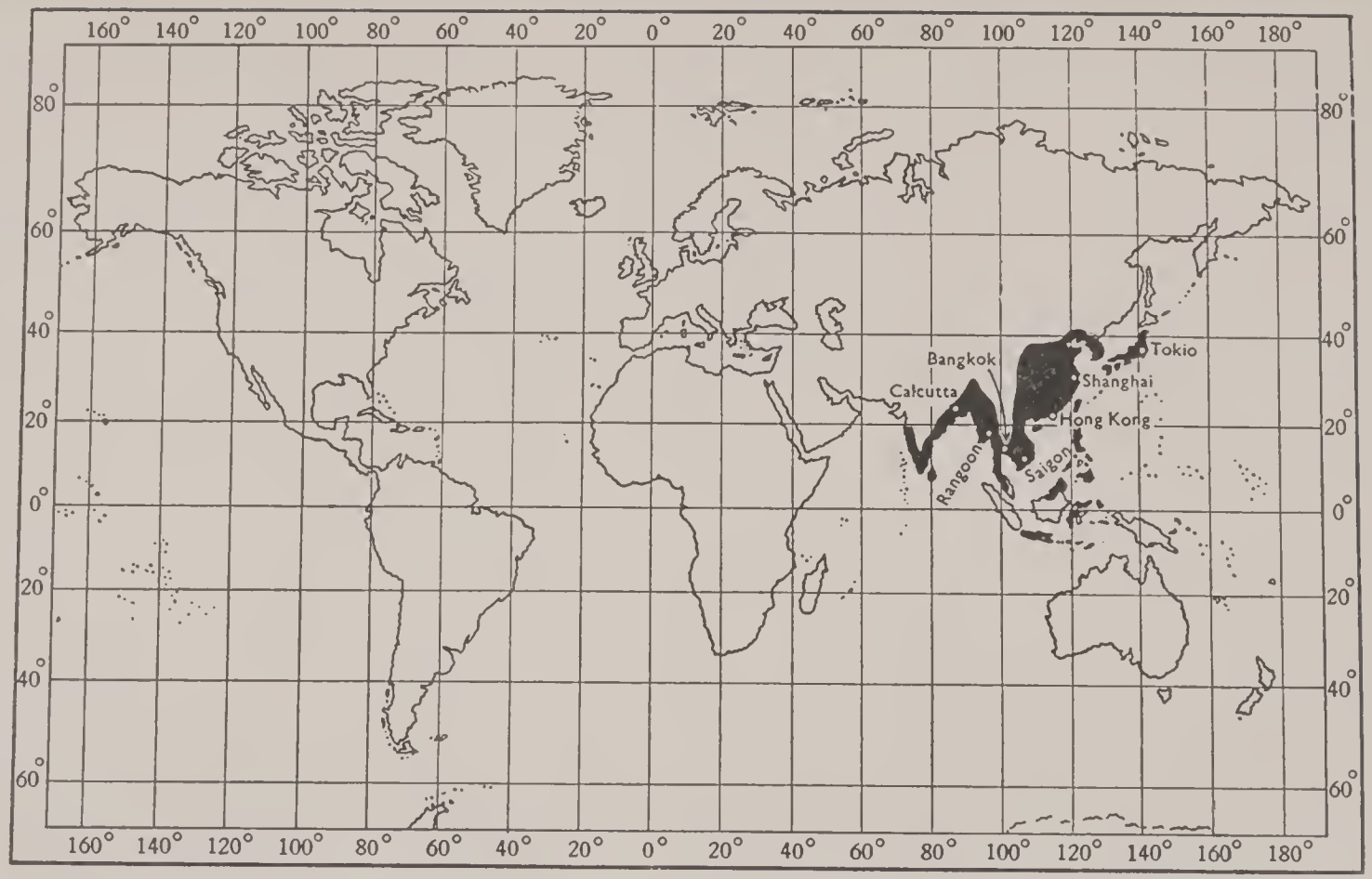


FIG. 34

The pre-eminence of Asia in rice production. The total world area under paddy is about 212 million acres; about 200 million acres or 95 per cent of this is within the heavily shaded regions. The climatic range of paddy production is within 40° of the Equator

will be under cultivation (an increase of 3½ per cent or 6 million tons). The Report states: "In terms of the standard of living of the people, the growth of productive power is not likely to show spectacular results by 1957 and the programmes will do little more than hold the present position. All the countries are expanding rice production, and the total increase may be of the order of 2,500,000 tons. India expects to increase production by 7 per cent, Pakistan by 6 per cent, Ceylon by 32 per cent, and Malaya by 77 per cent. This expansion will not, however, lead to uneconomic duplication. The total population of the area at the end of six years is likely to be some 10 per cent higher, and the increase in production envisaged in the programmes will to a large extent be taken up by the restoration of pre-war levels of consumption. On balance, it is estimated that the aggregate dependence of all the countries in the area on rice imports will be lessened by not more than 10 per cent, and that they will still have to import a total of 1,700,000 tons."

Outside Asia the cultivation of paddy has in recent years assumed growing importance, and there is reason to believe that if favourable prices are maintained, the area may be further increased. The area has been well maintained in Europe, but no very large expansion may be expected. A recent report on the possibilities of extending rice production in Africa[138] indicates that rice-growing may eventually be developed extensively. The possibilities here are, in fact, enormous, there being literally millions of acres of swamp jungle suited to the crop provided that irrigation and drainage are feasible. In Sierra Leone alone the available area is probably a million acres, and taking into account possibilities in Nigeria, the Gold Coast, and Gambia, the potentialities in British territories alone are almost incredible. In addition, vast areas of potential paddy-land exist in French Equatorial Africa and the Belgian Congo. The most ambitious scheme so far is that inaugurated by the French at Sansanding in the Niger bend, but others are in prospect. The main difficulties are lack of population and lack of capital; the possibilities of development, therefore, hinge to a considerable extent on mechanical development involving the outlay of considerable capital on water control and drainage. The area in Egypt has increased, but the largest increase in this continent is recorded from French West Africa, where the area under rice has practically doubled in the last decade. Yields are, however, low, and there should be ample scope for scientific work in African areas directed towards the improvement of yields.

In North and Central America, the United States is the only important centre of cultivation, and the war years saw a very considerable increase in the area planted, which will probably be well

maintained in the future. In South America a recent survey[26] reported that 368,000 acres of potential paddy-land exist in British Guiana. Several other countries in South America are suitable for the cultivation of paddy, but only in Brazil has the crop assumed an important position, almost comparable with some of the more productive areas in Asia. There is probably a vast area of land suitable for paddy cultivation in the Amazon valley, but in view of the sparse population, considerable capital would be necessary for mechanized development on a large scale. Work on an ambitious project to reclaim up to 500,000 acres of fertile swampland in Surinam (Dutch Guiana) has been initiated by a non-profit-making institution called into existence by the Netherlands and Surinam governments. The Dutch who will settle in this area will be engaged mainly in the production of rice on fully mechanized farms.

A recent survey has shown that extensive areas could probably be used for large-scale rice production without artificial irrigation in the Kimberley district of Western Australia and in the Darwin-Katherine area of the Northern Territory of Australia.[111]

To sum up the position regarding world areas under paddy: the areas under this crop in Asia have regained their pre-war position, but it seems unlikely that they will be extended to the degree necessary to keep pace with the growing demand. This conclusion is based on the past trend of increase in areas, on the growing competition of other crops that have a greater appeal to the Asiatics, and to the fact that the areas suitable for rice without additional expensive irrigation systems are necessarily limited. Most of the really extensive areas in Asia suitable for paddy cultivation are already planted under the crop. Some extension of the area planted may be anticipated in consequence of the awareness of the majority of governments of the dangers of the present position. There are indications that under the influence of international organizations and with the prospect of the provision of more adequate resources and funds for development considerable efforts will be made to extend rice cultivation and to ensure that the most efficient use is made of land suitable for rice cultivation. It is becoming widely appreciated that the aim should be self-sufficiency in rice production so far as it can be attained, and that to rely on imports from outside sources to satisfy increasing demands for rice may be to court the occurrence of shortages compared with which the present deficiency would be negligible.

WORLD PRODUCTION OF RICE

Table 12 below gives details concerning total crops and total acreages under rice for the years before the last war and for the year 1951. Prior to 1939 the total world crop of paddy was approximately 147¼ million metric tons, giving, after deduction of seed for future planting, approximately 94½ million metric tons of milled rice. During the war production diminished greatly in Asia and expanded in the Western Hemisphere. Although acreage and production had by 1951 exceeded again the pre-war acreage, the world is still losing at least 5½ million tons of cleaned rice annually on account of the unsettled conditions in Asia.

TABLE 12

WORLD AREA AND PRODUCTION OF PADDY AND RICE

Country	*Area* (thousand acres)		*Production* (thousand metric tons)			
			Paddy		*Rice equivalent*	
	1934/5–1938/9	1951	1934/5–1938/9	1951	1934/5–1938/9	1951
ASIA:						
British Borneo ..	682	775	170	163	102	108
Burma	12,184	9,429	6,971	5,500	4,601	3,630
Ceylon	750	1,124	340	330	224	220
China (22 prov.)	48,764	45,713	50,065	48,300	33,043	31,878
Manchuria ..	566	566	411		290	
Formosa ..	1,646	1,927	1,642	1,900	1,084	1,254
India	58,876	73,549	34,182	31,366	21,324	20,682
Indo-China ..	13,813	2,916	6,498	1,440	4,289	950
Indonesia:						
Java and Madura	9,495	9,852	6,081	6,125	4,013	4,042
Other islands ..	5,123	5,710	3,906	3,161	2,578	2,086
Iran	541	741	423	360	279	238
Iraq	386	519	205	180	135	119
Japan	7,831	7,422	11,501	11,302	7,591	7,459
Korea, South ..	3,005	2,261	2,726	2,105	1,799	1,389
Malaya (Fedtn.)	736	806	513	550	339	363
Pakistan	18,692	22,481	11,169	11,800	7,372	7,788
Philippines ..	4,917	6,092	2,179	2,831	1,438	1,868
Thailand ..	8,327	14,690	4,357	7,250	2,876	4,785
Total Asia ..	197,162	206,212	144,800	140,200	93,377	92,532

	Area		*Paddy*		*Rice Equivalant*	
	1934–9	1951	1934–9	1915	1934–9	1951
EUROPE:						
Bulgaria	20	—	19	—	11	—
France	—	44	—	70	—	46
Greece	5	49	4	56	3	37
Hungary	—	42	—	50	—	33
Italy	351	385	735	729	497	481
Portugal	51	77	66	141	43	93
Spain	116	148	293	285	193	188
Yugoslavia	7	7	4	7	3	5
Total Europe	550	752	1,121	1,370	750	904
AFRICA & OCEANIA:						
Belgian Congo	148	388	60	145	40	96
Egypt	430	506	609	620	402	409
Fr. West Africa	1,433	2,051	405	531	267	350
Gambia	—	62	—	22	—	15
Madagascar	1,235	1,604	613	816	404	539
Nigeria	—	423	—	250	—	165
Sierra Leone	346	788	187	275	123	181
Tanganyika	151	151	35	78	23	51
Zanzibar	—	22	—	16	—	11
Oceania	25	74	50	80	33	53
Total Africa and Oceania	4,571	7,413	2,180	3,200	1,479	2,112
NORTH & CENTRAL AMERICA:						
Cuba	44	136	20	105	13	69
Dominican Repub.	64	158	35	70	23	46
El Salvador	27	40	13	26	9	17
Haiti	—	—	3	31	2	20
Mexico	89	247	76	150	50	99
Panama	—	163	—	83	—	57
United States	955	1,947	956	1,987	631	1,311
Total North and Central America	1,179	2,940	1,180	2,550	728	1,683
SOUTH AMERICA:						
Argentina	44	138	51	191	34	126
Brazil	2,361	4,596	1,365	2,900	900	1,914
British Guiana	69	116	70	111	46	73
Chili	7	62	11	80	7	53
Colombia	138	390	99	380	66	210
Ecuador	150	180	66	105	44	69
Peru	106	136	86	215	57	142
Total South America	2,875	5,832	1,748	4,100	1,154	2,706
WORLD TOTAL (excluding U.S.S.R.)	212,012	233,262	151,200	151,500	99,792	99,990

No data are given for rice production in Russia, about which little is known in recent years. Before the war Turkestan and Transcaucasia provided about 75,000 tons of rice, while the total Russian consumption at that time was some 175,000 tons. Extensive developments were planned in the Far Eastern Region, Semirechensk, Transcaucasia, the Caucasus, and the Lower Volga, and it was expected that once necessary irrigation works had been completed the area would supply Soviet total needs and provide an exportable surplus. Test sowings in 1929 near the rivers Ili and Karataisk had shown that conditions for rice cultivation were excellent, and in 1930 a State farm was started to cultivate some 32,000 acres, using the waters of the two rivers.[276] One is unable to say whether these projects have materialized, but it would appear that the U.S.S.R. is now developing the cultivation of dry paddy, for according to Moscow radio[280] it is claimed that a new type of rice has been developed in the area east of the Volga. "This rice," continues the account, "grows on the dry steppe and does not require irrigated fields: it ripens a month ahead of the most rapidly developing rice, and does not require any water before harvesting." While there appears to be nothing "new" in this development of dry-land paddy cultivation, it is interesting to learn that the Russians are developing production along this line.

YIELDS

The yield of rice per unit of land varies considerably in the different countries of production, ranging from over 3,000 lb. per acre in Spain to about 500 lb. in Tanganyika. On the face of it, therefore, there appears to be good reason to conclude that the level of production could be materially raised in the countries of low yield, although the possibilities are necessarily limited in countries where production per unit is already high.

A number of reasons may be advanced to account for low yields, but the most obvious, easily appreciable by those conversant with conditions in Asia, is the hazard of unsuitable weather, especially in the absence of adequate control over drainage and irrigation. Accordingly, at least so far as Asia is concerned, the improvement of irrigation and drainage is the most important factor in raising the general level of production.

The second most promising is the improvement of seed supplies by selection. In many countries this has already given satisfactory results, and increases of yield from 25 to 30 per cent are by no means unusual. The facility with which this method can be applied has

tended to overshadow the possibility of evolving new and better varieties by breeding, and it is at least possible that by this method even greater increases of yield may be obtained ultimately although progress is bound to be slower.

Most authorities stress the importance of increased use of fertilizers if yields are to be raised, and the Food and Agriculture Organization of the United Nations is insistent upon this point; the factor of cost, however, is important, especially under Eastern conditions where cultivators are impoverished and it is still uncertain how far increases from fertilizer application are economic.

Improved methods of cultivation are also often suggested as a means of improving yields; the traditional methods of the East may be wasteful of labour, but none the less in the majority of Eastern countries they are sound in principle, and while modern implements and machinery may lead to more profitable crops through economies of labour they are unlikely to result in larger yields per unit area cultivated. No doubt there are exceptions; for instance, Mukerji[167] has stated that in India crop yields could be doubled by the use of improved seed and better tillage methods, and similar claims have been made in regard to China and Thailand, though with less justification.

The Asiatic system of continuous cropping of paddy-lands is also held by some to explain the lower yields compared with those obtained in new lands in South America under roughly similar climatic conditions. This may be correct, but the fact remains that some of the best rice-lands in the East have been cultivated under paddy for many years without manure and still continue to give high yields. As an example may be quoted an area in Malaya some 50,000 acres in extent, provided with a good irrigation system, which has been continuously cultivated in paddy for fifty years at least without manuring, and which continues to give annual yields little inferior to those recorded in Italy or Japan. The existence of such areas is one justification for hopes of greatly raising yields in Asia once the underlying factors responsible have been discovered.

THE EFFECT OF CLIMATE ON YIELDS

A fact that stands out is that yields obtained when the crop is grown in sub-tropical and warm temperate climates are generally higher than when it is grown under fully tropical conditions. It seems likely that this is primarily attributed to the longer day length during the growing period, coupled possibly with the occurrence of cold winters which may favourably influence soil conditions.

Contributory reasons may exist in particular countries; thus Italian rices are derived from strains imported from China and may, therefore, probably be long-day forms. Moreover, in most of the subtropical and warm temperate countries where rice is cultivated, the crop forms part of a regular rotation, a feature which is certainly conducive to high yields.

TABLE 13

YIELD OF CLEANED RICE* IN QUINTALS PER HECTARE IN DIFFERING DEGREES OF LATITUDE, NORTH AND SOUTH OF THE EQUATOR

Latitude 0 *to* 10°	*Latitude* 11 *to* 20°	*Latitude* 21 *to* 30°	*Latitude over* 30°
ASIA:			
Malaya .. 9·4	Burma .. 9·6	India .. 9·2	Iraq .. 9·5
Ceylon .. 5·7	Indo-China 6·7	China .. 17·8	Korea .. 14·6
Indonesia .. 9·7	Thailand .. 8·8		Iran .. 13·5
	Philippines 7·5		Turkey .. 19·7
	Formosa .. 17·0		Japan .. 25·8
			Manchuria 13·2
EUROPE:			
			Italy .. 31·6
			Bulgaria .. 17·0
			Spain .. 33·7
AFRICA & OCEANIA:			
Belgian Congo 5·1	French W.	Egypt .. 25·7	
Sierra Leone 9·3	Africa .. 4·8	Australia 31·5	
Tanganyika 4·9	Madagascar 8·5		
	Fiji .. 15·7		
NORTH & CENTRAL AMERICA:			
Costa Rica .. 7·7	Dominican	Cuba .. 9·7	United
Panama .. 8·8	Republic 9·2	Mexico .. 14·9	States .. 16·7
Colombia .. 7·6	El Salvador 8·3		
Trinidad .. 12·6	Honduras 8·4		
	Nicaragua 7·0		
SOUTH AMERICA:			
British		Brazil .. 10·5	Chili .. 21·0
Guiana .. 18·2		Paraguay 16·1	Uruguay .. 23·1
Peru .. 16·0		Argentina 22·1	
Surinam .. 18·9			

Nevertheless while admitting that yields may be affected by local secular factors, it seems inescapable that paddy is in fact better

* Conversion rate 70 per cent paddy equals cleaned rice.

suited to the sub-tropical and warm temperate zones than to the full tropics, notwithstanding that it is most widely grown there. Copeland[51] as long ago as 1924 pointed out that the highest yields were obtained in countries with temperate climates, but attributed this to the use of fertilizers, although, he added, "the difference is sufficiently great and constant to suggest that climate may be a factor." More recently Paul[184] has stated that "countries with a temperate climate give much higher yields than those in the tropics." On the other hand, Wickizer and Bennett,[271] discussing rice yields in Asia, appear to disregard the effect of climate and attribute the difference to such factors as the absence of flood and drought hazards, the use of manures, better seed, and better cultivation.

Table 13 shows the average yields of rice in the principal countries in which the crop is grown, classified according to the latitudes in which they are located, and brings out the point in question.

From the above data, which embraces all countries in the world where paddy is cultivated on an appreciable scale (except the U.S.S.R.), the following average figures of production are obtained.

TABLE 14

AVERAGE PRODUCTION OF RICE IN DIFFERENT COUNTRIES

Latitude (degrees)	*Average yield in quintals per hectare*	*Percentage of total world area in each category*
0 to 10	10·3	6·4
11 to 20	9·3	19·9
21 to 30	17·5	66·1
Over 30	20·0	7·6

From the foregoing table it seems permissible to conclude that the normal average yield of rice when the crop is grown in the tropics within 20° North and South of the Equator is in the region of approximately 10 quintals per hectare, while when it is grown in latitudes between 30° and 40° North or South it is in the neighbourhood of 20 quintals per hectare.

There are, of course, some anomalies. Thus whereas average yields in tropical Asia, Africa, and North and Central America between latitudes 0° and 10° are only in the region of 8 quintals per hectare, the average for the South American states within these latitudes is about 18 quintals per hectare. A point that may have some bearing here is that the paddy soils of British Guiana and Surinam

are very rich in organic matter, a point that also applies to the very high-yielding area in Malaya referred to on page 267, and the result may at least in part be attributed to this. In other South American states two paddy crops per annum are obtained in some regions, while in others conditions are such as to make it possible to plant and reap paddy at any time of the year. Among Asiatic countries within these latitudes Formosa is remarkable for its high yields; but here much of the land yields two crops per annum, cultivation standards are very high, and heavy manuring is extensively practised.

Of the countries lying between 20° and 30° North and South, the majority conform reasonably to the criteria, with the exception of India, Cuba, and Brazil. So far as concerns India it appears highly probable that with better cultivation, better seed, and improved water control yields could be materially increased. Indeed if Indian yields could be raised to the level assumed to be characteristic of these latitudes it should go far to lessen apprehensions of a world rice shortage for some years to come.

Of the countries lying between 30° and 40° North and South, the United States alone calls for comment. Most of the countries within this range show yields of well over 20 quintals, but the average yield in the U.S.A. is only 16·7. There is little doubt that for this the system of cultivation is largely responsible, and so long as it remains more economic to continue to follow existing methods yields per unit area will continue to lag behind those in other countries with comparable conditions.

THE POSSIBILITY OF RAISING YIELDS

If it is admitted that the environmental factor is dominant in determining the magnitude of production, it becomes possible to assess the limitations to potential yield increases for any particular area, and conversely to determine where by the application of accepted methods increased yields may be anticipated. Thus while it must always be admitted that local influences require to be taken into account, it should be possible to raise yields in latitudes between 0° and 20° to 10 quintals per hectare, and in latitudes between 20° and 40° to 20 quintals per acre. The figures are, of course, generalized and do not rule out the possibility of an all-round increase above these limits as a result of cultural, manurial, or varietal improvements.

But even if only this potential was attained it would materially affect the production of rice in the world. About 26 per cent of the world area under paddy is grown between 0° and 20°, 66 per cent

between 20° and 30°, and the remainder in latitudes over 30°. Consequently it appears at least possible that improved methods might lead in the aggregate to the production from existing paddy areas of a total world crop of 200 million metric tons of rice, or roughly double the present out-turn. The estimate may appear unduly optimistic, nevertheless the data on which it is based are so striking that one cannot but feel that it is justifiable.

To exemplify some of the possibilities, Burma, Indo-China, and Thailand are the main rice-exporting countries. They all lie between latitudes 11° and 20° North; their average production per hectare is respectively 9·6, 6·7, and 8·8 quintals. If this could be raised to 10 quintals per hectare it would add about $2\frac{1}{2}$ million tons of rice to available supplies.

It is unnecessary here to discuss in any detail the various means available for improving production, since they have been dealt with in previous pages. It may, however, be appropriate here to stress that of all the methods available the simplest and the cheapest is the improvement of seed supplies.

In vast areas in Asia the varieties cultivated are so mixed that marked improvements in yield can be obtained in one or two seasons by field selection based upon a single character. From a practical point of view the aim should be the cultivation of a single strain in any one field, thereby eliminating the competition which is bound to arise when a number of different forms are grown together, e.g. tall forms and short forms. Mass selection has been recommended as a sound first step; pure-line selection is more arduous but has been followed in many countries, and although the results have not always been uniformly satisfactory, it has in many cases led to marked improvements in yield. In Thailand, for example, the increases which have resulted from its employment are stated to amount to 15 per cent, while in Malaya they are put at 25 per cent.

The production of new rice varieties by hybridization may be expected in the long run to give the best results, since not only can it provide higher yielding types, but it can also eliminate or reduce losses from lodging and improve resistance to pests and diseases. The production of hybrids is long-term work of a very laborious character; it demands a high degree of skill and much more precise knowledge of the characters of existing strain than is at present available. The characters require to be classified and catalogued so that the performance of each type under different environmental conditions can be better understood. Nevertheless such work is likely to be amply rewarding. It has produced spectacular results in the case of wheat for example, and there does not appear to be

any obvious reason why equally striking results should not follow its application to rice.

Under field conditions selected strains do not remain pure indefinitely; they tend to become mixed with seed from other sources. Moreover, experience with other cereals shows that varieties may evince a certain mutability under continuous cultivation. Disease-resistant varieties may exhibit diminution in their powers of resistance owing at times to changes in the diseases themselves. For all these reasons it is necessary periodically to supply growers with fresh seed supplies, and this necessitates continuous effort to enable these to be produced and distributed to growers.

Under Asiatic conditions the limiting factor to yield improvement through seed improvement is probably the low educational standard and the apathy of the cultivators, which make them not so much antagonistic to improvements, but slow to absorb new ideas and to appreciate the possibilities of improvement.

In some quarters concern has been expressed[206] at the apparent decline in production per unit of area in Asia of recent years. Table 15 gives some data in this regard.

It has been asserted that "lack of good seed, fertilizers, and other requisites continue to affect the productivity of the rice-land under cultivation. Restoration of damaged irrigation and drainage systems in war-devastated areas is being carried out, but progress is slow and is conditioned by the shortage of necessary machinery and equipment. The heavy slaughter of cattle for food in the enemy-occupied territories and the havoc caused by the rinderpest epidemic have reduced the number and efficiency of work animals, and this has adversely affected the preparatory tillage of lands under cultivation. All of these factors have contributed to the decline in yields." The damage resulting from the Japanese occupation is indeed serious, for many paddy-fields were allowed to revert to waste land and it may be some time before they can be brought back to a high state of cultivation. The absence of fertilizers, however, can hardly affect the situation since in most Asiatic countries they are not employed for paddy, while machinery and equipment for paddy cultivation are of the simplest and are easily replaced. Machinery and equipment may be required to repair irrigation works, but such works cover but a small percentage of the total area of paddy in Asia.

It is easy to exaggerate the significance of the variations in yield shown in Table 15. Statistics of food production in Asia are in many cases not very accurate. Many of the technical workers and production specialists in India, for instance, are emphatic in their

belief that the crop reports in recent years have underestimated total production. They stated[76] "that average yields of food crops, especially rice, are at least stable as compared with pre-war and, if moving in either direction, are increasing gradually with improved varieties, cultural methods, and fertilizer use." As a direct result of the war, both total production and yield per unit area have been affected, and there has been loss of planted area in some regions.

TABLE 15

AVERAGE YIELDS OF PADDY IN THE PRINCIPAL RICE-PRODUCING COUNTRIES OF ASIA
(in quintals per hectare)

	1934–8	1945	1946	1947	1951
Burma	15·0	10·7	11·8	14·9	14·4
China	25·3	22·4	25·5	25·4	—
Formosa	26·3	—	16·1	20·5	24·4
India Pakistan ..	13·3	12·4	13·0	12·8	11·1
Indo-China	11·2	—	10·5	10·8	12·2
Java and Madura ..	16·0	—	14·7	15·0	15·3
Japan	36·3	27·9	36·9	35·7	37·6
Korea	23·6	22·8	20·4	23·6	23·0
Philippines	10·9	9·8	10·8	10·7	11·1
Thailand	15·3	12·7	13·1	12·7	12·8

This and the continued unsettled political conditions throughout the East (which has affected every country mentioned in Table 15) militate against an early recovery of the industry, and have been mainly responsible for the apparent decline in yield. It is certain that, given an improvement in the political sphere, the planted area will quickly regain normality, and crop yields show a rapid improvement. Thereafter, the tendency should be towards a further increase in yield, due mainly to better drainage and irrigation, wider distribution of improved strains of paddy, and the more adequate control of insect pests.

To sum up: one of the main factors governing the yield per unit of land is climate, it being held that the paddy plant is only capable of yielding its maximum crop under sub-tropical or warm temperate climatic conditions. While, therefore, paddy grown under tropical conditions may possibly not be capable of giving the high returns possible in more temperate climates, the yields in most countries still fall short of the optimum that should be expected under their particular environmental conditions. It is probable that they can be

raised to a higher level in most countries of Asia by the planting of improved seed, better cultural methods, and at least in some regions —probably in all—by the extended use of natural manures and artificial fertilizers. It has been estimated in some quarters that yields might be raised by at least 25 per cent by the planting of improved seed. Further very material gain could be expected from improved drainage and irrigation, and also from the prevention of excessive loss through the depredations of pests in the field and the store. Taking all these factors into consideration, together with others of less importance, the aggregate increase in crop might easily be of such an order as to justify the present writer's contention, arrived at on theoretical grounds, that the potential crop from the existing world area under paddy might be double that at present obtained.

CONSUMPTION

The people of Asia are not only the largest producers but also the largest consumers of rice. The form of cultivation practised in the East necessitates a very great expenditure of labour, and accordingly the cultivation of paddy is general in regions of dense population. Hand labour, together with the lack of capital, limits the amount of land that any one owner can cultivate, the area cultivated as a unit is therefore very small, usually from one to six acres. The cultivator in most regions grows rice primarily to supply his domestic needs. Part of the excess crop, if any, he may store for future need should the next crop be insufficient, and for seed for the coming season. The remainder is sold for local consumption and, after this market is satisfied, the remainder is available for export outside the country of origin.

TABLE 16

PRE-WAR AND POST-WAR SOURCES OF RICE EXPORTS
(thousand metric tons)

Exporter	*Average* 1934–8	*Percentage of total*	1951	*Percentage of total*
Burma	3,070	38·8	1,325	27·0
Thailand	1,388	17·6	1,612	32·8
Indo-China	1,320	16·7	334	6·8
Korea	1,091	13·8	—	—
Pakistan	393	5·0	205	4·2
Italy	111	1·4	231	4·7
Egypt	97	1·2	313	6·4
United States	72	0·9	491	10·0
Brazil	54	0·7	165	3·4
Others	304	3·9	236	4·7
Total	7,900		4,912	

It is probable that the producer's family consists on the average of six persons, who together will consume about 1,800 lb. of rice a year, that is, the produce of about two and a half acres of land. Add to this the consumption of rice by the non-producers in the area, and one realizes why the exports of rice even from the extensive areas such as exist in Burma, form a relatively small proportion of the total production. This great expenditure of labour also limits the effectiveness, from the point of view of providing rice for export, of the development of new areas.

Taking Burma as an example of a region of great production and export, the facts are as follows. Before the Second World War Burma cultivated almost 12½ million acres of paddy, and after deduction of seed required to plant in the succeeding season, about 4,587,000 metric tons of cleaned rice was obtained. But of this total she was able to export only a little over 3 million tons, or 67 per cent of the total production. With a post-war fall in production to less than 3½ million tons, Burma in 1951 was able to export only 1,300,000 tons, 37 per cent of total production.

TABLE 17

RETAINED IMPORTS OF RICE IN PRINCIPAL CONSUMING COUNTRIES
(in thousand metric tons)

Country	*Average* 1934–8	*Percentage of total*	1951	*Percentage of total*
ASIA:				
India	1,828	23·3	783	15·9
Japan	1,732	22·1	784	16·0
China	610	7·8	20	0·4
Malaya (Federation) ..	540	6·9	527	10·7
Ceylon	530	6·8	413	8·4
Indonesia	261	3·3	500	10·1
Hong Kong	175	2·2	210	4·3
Philippines	35	0·4	111	2·3
U.S. Pacific Territories ..	—	—	116	2·4
Other Asiatic Countries	97	1·2	256	5·2
Total Asia	5,808	74·0	3,720	75·7
Total Europe	1,230	15·7	445	9·0
Total Africa	400	5·1	159	3·2
N. and C. America ..	310	4·0	319	6·5
South America	100	1·2	120	2·5
Unspecified	—	—	149	3·1
Total	7,848	100·0	4,912	100·0

Practically all countries in Asia are producers of rice, but only five are in a position to export rice; the remainder are under the necessity of buying rice from other countries to supplement local production. The five exporting Asiatic countries are Burma, Viet Nam, Thailand, Korea,* and Formosa. Small amounts are also exported from certain European countries, Egypt, the United States, and Brazil. However, over 70 per cent of exports are derived from Asiatic countries. The pre-war and post-war sources of rice exports are shown in Table 16.

Seventy-five per cent of total world exports of rice are consumed in Asia, as is shown in Table 17. In a normal year the four important exporters send rice to other Asiatic countries, and failure to do so spells undernourishment in the importing countries, for as is seen from Table 12 alternative sources of supply are quite unable to make up any deficiency.

THE POST-WAR POSITION

The area planted in Asia in the first post-war year (1946–7) was 188½ million acres, being nearly 4¼ million acres less than before the war. Increased planting in other parts of the world covered this deficiency, but the total production showed a decline of 3¼ million metric tons of milled rice, due entirely to a drop in production per unit of area in Asia. Shipments of rice from exporting countries were 1·9 million tons in 1946 and 2·2 million tons in 1947 as compared with 8·3 million tons per annum before the war.

Whereas before the war 70 per cent of rice exports came from the three countries Burma, Thailand, and Indo-China, the Japanese occupation of these countries denied the world these sources of supply, while such were the Japanese shipping difficulties they were unable to move any considerable quantities of rice to supply the needs of the deficient countries they occupied.

During the war years production assumed growing importance in the Western Hemisphere and in the immediate post-war years the world has had to rely to a large extent on the maintenance of supplies from this region, for in the first post-war year Burma was able to export but 12 per cent, and Thailand 33 per cent of pre-war averages. Before the war the United States exported about 205,000 tons, including shipments to its own territories. In 1951, however, it exported 491,000 tons, most of which went to Cuba, China, Korea, and the Philippines. More than 28 per cent of the 4·9 million tons that did move in international trade came from the United States, Ecuador, Mexico, and other non-Asiatic countries.

* Since the outbreak of war in that country, Korea has ceased to export rice.

With the recovery of rice production in Asia international trade has resumed more of its pre-war pattern, especially in view of the foreign exchange problem, as Asia can produce rice at a competitive price with the Western Hemisphere. The unsettled political condition of several important rice producers in Asia, however, militates against the early recovery of these countries as rice exporters, and until they become politically stabilized, international trade in rice must be dislocated, supplies remain short, and the East will continue to rely to some extent on the new sources of supply in the Western Hemisphere.

Short supplies plus trade difficulties mean that many people must go hungry. To alleviate distress and to ensure that available supplies are fairly allocated, the international movement of rice in the immediate post-war years was governed by an allocation system, at first under the Combined Food Board, followed by the International Emergency Food Committee. No shipments of rice to European countries were made in 1947, but for the first half of 1948 token shipments totalling 61,000 tons were allowed at the wish of the exporting countries. In 1951 imports of rice into Europe mounted to 445,000 tons (not necessarily all from Asia).

The Food and Agriculture Organization of the United Nations (F.A.O.) state that there are two aspects of the problem of satisfying the growing demand for rice in Asia: firstly, to restore the cultivation of paddy in Asia to its pre-war level, and to maintain efforts to make the best use possible of supplies in the interim, and secondly to devise methods of raising production to a higher level than ever before to ensure supplies adequate to keep pace with the ever-growing population of rice-eaters in the East.

Though the surplus-producing countries that exported over 8 million tons of rice annually before the Second World War but exported less than 2 million tons in 1946 have been able gradually to increase their exports to 5 million tons in 1951, it is highly problematical whether further significant advances to pre-war export levels can be made in the present unsettled conditions of South-east Asia. Seven years after the war, one-quarter of Burma's pre-war paddy acreage still remains abandoned to jungle growth. The main reasons for hopefulness are that the large body of growers depend on the sale of paddy as their sole money crop, that large tracts of land on which the crop is grown are unsuited to other forms of cultivation, and because the respective governments of rice-exporting countries in Asia realize that a large part of their revenue depends on rice exports; they will, therefore, make every effort to maintain and expand this trade. In the meantime, the pre-

sent organization to ensure fair distribution of available supplies must continue in being. It has become imperative to eliminate waste of paddy and rice as far as possible. Figures placed before the International Rice Meeting at Baguio[212] in 1948 indicated that "more than 10 million tons of rice are lost annually, principally through the following causes: (*a*) insect and rodent infestation; (*b*) faulty methods of storage at all stages; (*c*) wasteful milling; and (*d*) current methods of household preparation." It is, of course, quite impossible to give an accurate figure for the amount of rice lost annually from the causes stated, and one must regard such an estimate as an informed surmise. But it emphasizes the undoubted fact that the losses from the causes mentioned are widespread and very serious; they are losses that cannot be tolerated at a time when so many people are hungry. One might add to them, losses occurring in the field, chiefly by insect pests, such as stem borers and paddy bugs, by rats and birds, as well as losses due to faulty handling of the crop at harvest.

The problem of increasing the world production of rice is more difficult than is the immediate problem of distribution of present supplies. According to the F.A.O., the rate of increase of the basically rice-eating population of the world approximates to 10 million each year. In order to feed these additional people, world production of rice must be increased annually by at least 1·3 million metric tons (milled or cleaned basis).[206] The rate of increase in population in the densely populated areas of Asia depends on available food supplies; when undernourishment, if not actual starvation, prevails, the rate of increase slows down, whereas in times of plenty it increases more rapidly. The present troubles in Asia, therefore, are likely to slow down the rate of increase in population for a time. It is not, of course, suggested that the present situation is not serious, or that considerably increased supplies of rice will not be required in the future. The demand can be met in two ways; either by increasing the yield per unit of area and/or the total area under paddy. As has already been stated, there are great possibilities of increasing the yield per unit of area, both in Asia and elsewhere, and it would appear that development in this direction might lead to earlier results than would the increase in area under the crop. It is obvious, however, that rice production cannot increase indefinitely at the rate of over a million tons a year; the ultimate solution of the problem seems therefore to be limitation of population either by natural causes or by birth control.

Increases in the area cultivated under rice in Asia are possible and indeed are to be expected; the main difficulties are to find sufficient

supplies of suitable and easily irrigable land and an adequate population to work them by present methods. Should, however, the present attempts to mechanize cultivation prove successful, there are possibilities of development in areas at present considered unsuited to paddy. Even in the surplus-producing countries of Burma, Thailand, and Indo-China, extensions are possible, though this will entail capital outlay, particularly for irrigation and drainage, which may not be easily forthcoming. Extensive areas of suitable paddy-land are also said to exist in most other Asiatic countries, though it is not clear whether such land is also suitable for other forms of cultivation. Hitherto, the general rule has been to consider that other crops have priority over paddy, but it may well be that with the growing demand for rice, and with better prices for this product, governmental policy and economic considerations may lead to a wider conception of the classes of land deemed suitable for paddy cultivation.

Should investigations lead to the improvement of varieties of dry-land paddy, this crop could then take its place in rotation with other dry-land crops, and the area cultivated with paddy would thereby increase. This must be considered a long-term view of the problem, for as yet there appears little evidence that work is in progress towards the improvement of dry-land paddy varieties. The potentialities of dry-land paddy should not be set aside before the issue has been decided as a result of searching investigation into the methods of cultivation and of the varieties suited to this form of cultivation. The popularity of dry-land paddy cultivation in certain parts of South America points to the desirability of investigation in these countries.

The potentialities of rice production in Africa and the Americas are immense, and there is little doubt that given a favourable and fairly steady price for rice, significant increases in area may be expected in the next decade or so.

PRICES

The price of rice is quoted in terms of cleaned or brown rice and not as paddy, and at first sight rice would appear to be the most expensive of the cereals, though tariffs and other methods of control may change the price relationship. It is consistently higher in price than the inferior cereals such as oats and rye, while for many years it has tended to become cheaper in relation to wheat. Rice prices are less variable than are wheat prices because, apart from loss of crop on account of climatic conditions, the area planted is approximately the same each year, and there are no alternative crops suitable

for cultivation on the paddy-growing areas. The paddy-grower, therefore, has no alternative to the production of his annual crop of paddy.

The miller is guided in the price he pays for paddy by the type of rice and the expected milling results. Naturally he is anxious to obtain the greatest possible quantity of paddy of any one particular type. Any one grade of rice is not necessarily obtained from a single variety of paddy, though to obtain uniform grade varieties of paddy of similar nature are necessary. Frequently the price of paddy shows seasonal fluctuations, depending upon the quantity of paddy held by growers and the competition for supplies by the millers.

Thailand rice on the Eastern market commands the highest price, Burma rice takes second place, while that from Indo-China is at a further discount. The popularity of rice, however, varies somewhat in different countries; in Japan, for instance, domestic rice obtains premium prices, rice from California being at a discount, and Indo-China rice at a further discount.

The price of rice of different grades from the same country of origin reflects largely the content of broken grain. This broken-grain content is no chance characteristic, but is carefully controlled at the mills. Other factors in judging quality from a commercial standpoint are colour and uniformity of the grains, foreign matter, amount of chalky grain, unevenness of type, and general appearance.

Asiatics have very strong likes and dislikes regarding rice, tastes differing considerably on a national basis. Wickizer and Bennett[271] state:

> The basis for such highly developed preferences is not wholly clear. Why the Japanese prefer one flavour and the natives of Thailand another appears to be based partly upon tastes that have been developed over generations. Rice varieties adapted to the soil and climatic conditions of one region probably possess flavour characteristics differing from those adapted to other regions. When conservatism is so strong in matters of taste and when the population tends to be immobile, the local consumer might well be inclined to regard rice grown in more distant regions and possessing different flavours as in some vague sense inferior. Furthermore, the extent to which rice is consumed in the Orient tends perhaps to develop discriminations beyond the comprehension of the typical Western consumer.

The purchasing power of rice has a profound effect on the well-being of the Asiatic. During the third decade of the present century this purchasing power declined in comparison with the second decade; while this was to the advantage of the non-cultivator consumer, it caused distress among the growers. It appears probable that prices may continue to favour cultivators for some time to

come; if this be the case it would provide an excellent opportunity for governments through co-operative societies to assist the cultivators to place themselves on a sound economic position to face the future fluctuations in the fortunes of paddy cultivation.

GOVERNMENT INTERVENTION IN THE RICE INDUSTRY

Government intervention in the rice industry may either aim at stimulating production with the object of improving the lot of the cultivator, or at attempting to make the country self-sufficient so far as rice supplies are concerned. Such interventions in most countries have proved very costly and have usually not produced results commensurate with the cost. Manipulation of the market price of the product, either in favour of the producer or consumer—or both!—is of no lasting benefit to either producer or consumer. In a crisis, however, stocks and prices are justifiably controlled, but in normal circumstances a healthy industry is one that can stand on its own feet. Lack of organization amongst producers together with lack of capital often places them at the mercy of a chain of organized buyers; this and the paramount necessity of maintaining and increasing the production of rice may, however, provide sufficient justification for governmental intervention, distasteful as this is from many points of view. One therefore prefers to look upon government intervention as an interim means of alleviating the condition of producers and protecting the consumers, pending a sounder solution of the problem that can only come to pass when the producer is educated in the principles of co-operation, whereby he may build up capital for production and exercise control in the sale of his produce. In the meantime, governmental intervention (if possible of a paternal nature) must be accepted as a palliative, but should not be considered as an alternative to the independence of the cultivator, for the best cultivator is the one most conscious of his independence.

Note: The subject of this chapter has been exhaustively treated in *The Rice Economy of Monsoon Asia* by V. D. Wickizer and M. K. Bennett.[271] For this reason it has been treated but briefly in this chapter. The author has freely used facts and figures from the above-mentioned publication and from publications of the F.A.O.

Chapter XVII

ECONOMIC CONDITIONS

Land Tenure — Indebtedness — Cost of Production — The Policy of Self-sufficiency—Financing the Cultivator— Betterment of Economic Conditions.

As over 90 per cent of the world supply of rice comes from Asia, the economic position of the Asiatic cultivator must profoundly affect world supplies of this important foodstuff.

The most important factor affecting the area cultivated and the yield per acre is the unsatisfactory economic position of the Asiatic cultivator. The development in south-east Asia of large-scale cultivation of export crops such as rubber, which has attracted the small-scale rice producer, resulted in neglect of paddy in favour of these new and attractive crops, while the pre-war price of rice was so low that cultivation was uneconomic except in the more favoured areas. The competition of other crops with rice was most pronounced in regions where paddy was not the sole or indeed the major crop. It was less felt where vast areas of land were planted in rice under conditions unsuited to alternative crops; therefore, despite the attraction of other crops and the unsatisfactory price of rice, paddy cultivation has persisted and in some regions extended.

LAND TENURE

The two major factors responsible for the continued unsatisfactory condition of paddy cultivation are: (*a*) the conditions under which the cultivator holds the land and (*b*) his financial instability. An examination of systems of land tenure and of finance is, therefore, necessary for an appreciation of the difficulties and discouragements facing the cultivator.

Systems of land tenure vary considerably throughout Asia, and in many cases, as in India and Ceylon, are complicated by the local laws relating to inheritance of property.

BURMA

The extensive paddy-fields of Lower Burma have been brought into cultivation since the year 1870. To develop this sparsely populated area the government encouraged immigration from Upper Burma and from India by giving leasehold rights on land after continuous payment of land revenue for a period of twelve years. In Upper Burma, extension of paddy cultivation has been due mainly to irrigation works carried out by the government.

CEYLON

It is the rule rather than the exception for paddy-land to be owned in Ceylon by non-cultivating landlords; in fact, about 75 per cent of the land is so held. Except in the areas served by the major irrigation schemes, where the unit owned may be 50 to 100 acres, ownership is generally in areas of about five acres, while the average area under individual ownership is about half an acre only. In many cases[184] ownership is complicated by the fact of "infinitesimal" shares, due to the custom of equal inheritance of property, with the result that the fields are cultivated on the system of alternate cultivation by the co-owners, in which each owner cultivates the land for one season and takes his turn again when the full round of co-owners have each had their turn. A further complication is that owners are usually non-resident, or have a number of fields in scattered places, the cultivation being carried out by tenants.

The average holding of a tenant is from half to three-quarters of an acre. There are three main systems of tenancy, viz. the share system, the system of fixed rent, and the hire system of cultivation. Under the share system the fields are leased out for one or more seasons, generally on a half-share basis of the crop, which is divided at threshing time after deduction for such items as seed paddy and hire of buffaloes, which are usually provided by the owner. In the system of fixed rent, the rent is paid in kind or in cash. The amount varies with the district and in some cases with the season. Under the hire system of cultivation the owner engages labour for all operations and pays for the work with a part of the crop, or the produce from a definite area under cultivation.

MALAYA[91]

In Malaya, all land which is not alienated, or reserved for a public purpose, or reserved forest, or held under a government licence for temporary occupation, or under an approved application, is State Land. State Land is divided into five categories, one of which is "Country land not exceeding 10 acres in extent," and it is under this category that most of the paddy-land falls. The title to such land is

either Grant or Lease, for which the lessee pays to government a fixed annual rent. As an inducement to cultivate foodstuffs, an annual rebate is allowed on so much land as can be proved to have been planted with paddy or other approved products. To protect the paddy-planting industry the government now makes a condition that only paddy shall be planted in specified areas which are considered suited to this form of cultivation. Further, to ensure that the needs of the indigenous population are adequately guarded, the Malay Reservation Enactment gives powers to the government to declare an area to be a Malay Reservation, in which the land cannot be sold to a non-Malay. A great deal of the paddy-land is situated within such Reservations, and as practically the entire paddy area is cultivated by Malays, the cultivator is safeguarded against loss of ownership. A somewhat similar system obtains in Indonesia, where the government owns the land and leases it to the native cultivator, who may not transfer ownership except to another native cultivator.

Thailand

As in Malaya so in Thailand, all land is vested in the state and may be alienated to individuals for the payment of a premium, survey fees, and an annual rent. Usually for paddy-land these fees may work out to about five shillings an acre.

The tenure from government is freehold. Landlordism exists, more so in the Central Plain than elsewhere in the country, and even in the Central Plain the amount of land rented is not considerable except near Bangkok where most is rented. Here the landlord takes but little interest in his property or in his tenants, while the latter are usually under a one-year tenancy and take all they can from the land with little or no respect for the condition of the land at the termination of their tenancy. Disputes and frequent changes of tenants are common and altogether the position is considered most unsatisfactory. Terms of tenancy vary and rent may be paid in cash or in paddy. A typical rate is 50 per cent of the crop to the landlord, who pays the land tax due to the government. The usual cash rate is three *bahts* per *rai* (about fourteen shillings an acre), the tenant paying the government dues. Alternatively, the landlord may charge a fixed rent in paddy for which an agreed area is rented, the landlord may or may not pay government dues according to the terms of the tenancy.

The land tax payable to government is usually at the rate of about eightpence per acre and may be as low as about sixpence for the poorer land. Land values vary according to local circumstances, but typical figures are about £5 to £10 per acre, the higher figure being

the more common, but in the "floating rice" regions where yields are heavy, the land may change ownership at rates corresponding to £35 to £70 per acre. There would appear to be no particular difficulty in finding tenants or in colonizing new areas, but no special inducements are offered or considered necessary to attract settlers.

The average size of holding in the Central Plain is about 12 acres; a holding of 8 acres would be considered small and holdings up to 20 acres are farmed, while there are holdings of over 40 acres managed by a family unit. In the non-commercial areas the holdings are smaller, the owners being concerned merely to grow sufficient rice to satisfy home needs. Holdings of over four acres are the exception, although in the north they tend to be larger.

In the Central Plain the land is excellent for paddy cultivation, but practically useless for other crops. The government imposes no conditions on the cultivator as to the crops he should or should not grow, but the cultivator, traditionally a paddy planter, would be unlikely to consider the cultivation of other crops.

INDO-CHINA (CAMBODIA, LAOS, VIET NAM)

The nature of the tenancy and the size of the holding vary considerably in Indo-China. In Tonkin, peasant ownership is general; about 61 per cent of the holdings are one acre or less in size, 30 per cent are between one and five acres, and only 9 per cent exceed five acres. In Annam, the holdings are rather larger. In Cambodia, although small holdings are still in the majority, the average size is again somewhat larger. Only 36 per cent are $2\frac{1}{2}$ acres or less in size, 52 per cent are between $2\frac{1}{2}$ and $12\frac{1}{2}$ acres, and 12 per cent exceed $12\frac{1}{2}$ acres. In these territories, with the exception of Cambodia, there is a dense population, consequently numerous small-sized holdings are the rule. In Cochin China, rice-growing is of more recent development and large estates are common.

The peasant is normally the owner, but in Cochin China 65 per cent of the 255,000 holdings are worked on a tenancy basis. The rent is usually upwards of one-half of the crop reaped from land of average fertility. If buffaloes are hired from the landlord, a rent in cash or kind is also charged.

The scale of land taxes appears to vary in each of the five territories. In Cochin China, for example, the gradation is dependent on the quality of the land and varies from 10 cents (Indo-China) per hectare in the case of newly cleared unimproved land to 2 piastres per hectare for first-class paddy-land. In Cambodia there are seven grades of taxes ranging from 20 cents (Indo-China) to 3 piastres per hectare.

China

Land in China[33] is almost entirely privately owned, only 7 per cent being held by the state.* It is mostly in the hands of individuals, less than 1 per cent being owned by the temples and family clans and leased to tenants. Somewhat less than three-quarters of the privately owned farm land is owned by the actual farmers, while about one-quarter is rented. The owner-farms average about 4 acres, tenant farms 3½ acres; therefore, over half the number of farmers are owners, less than one-third part-owners, and 17 per cent tenants. Tenancy is more prevalent in south China than in the north.

Some of this privately owned land, held in large amount by single landlords and leased to farmers, constitutes one of China's major problems. Buck states: "The greater amount of tenancy in the Rice Region may be caused by the greater accumulation of wealth, the better communication and transport facilities, and the concentration of population. People with accumulated wealth have until the last decade invested it in land for the return it will bring, for the safety of the investment, and for the social prestige of its ownership." He adds that a change of system of land tenure cannot be expected to affect the amount of land cultivated or result in increased crop production, for it has been found that the tenants are better farmers than the owners.

Fragmentation of land, i.e. the ownership by individuals of scattered pieces of land, is the rule in China. While the number of such areas of land are unknown, there are usually six pieces per farm, averaging a little less than an acre. This leads to wastage of land, loss of time, limits the use of machinery, and makes crop production difficult. Labour, however, is cheap, so that machinery is not greatly in favour. The wastage of land in China is, however, enormous. It is estimated that about 25 million acres more could be cultivated by the removal of graves from cultivatable land, the elimination of land in boundaries, the consolidation of fragmented holdings, and the cultivation of suitable land not now cultivated.

The farmer in China also suffers from high taxation. The taxation is high because it is easy to collect, and because of the wasteful methods of tax collection. While the taxation is based on the kind of land, the rate bears little relationship to the productivity of the land.

Japan

Conditions in Japan are somewhat similar to those obtaining in

* Conditions relate to about 1937. Changes effected by the present regime are not known. It is believed that great changes in land tenure have been effected, including the elimination of fragmentation of land.

China. About three-fifths of the paddy crop is grown under the tenant system, the landlord receiving his rent in kind. The area of land farmed by one cultivator is usually less than an acre.

INDONESIA

All land in Indonesia is owned by the government. Land suitable for paddy cultivation is leased by government to Indonesians, who may not transfer their ownership rights to any but Indonesians. In the sugar-producing areas, government provisions of tenure compel a rotation in which sugar is grown on the land for one year in three or four, paddy three times in two years. If ample irrigation is provided, other crops in the rotation may be maize, cassava, sugar, sweet potatoes, and groundnuts.[143]

The above notes on land tenure in parts of Asia are typical of the complexities evident throughout the continent, and illustrate some of the very grave difficulties encountered by the cultivator. Reflection will make evident the improvements that would inevitably follow if some of the more one-sided agreements between landlord and tenant could be removed. The poverty of the cultivator is mainly responsible for making him dependent on the goodwill of the landlord, a goodwill that is maintained on account of the large share of the profits enjoyed by the latter. The following conclusion of the F.A.O. Mission to Thailand in 1948[209] may be held to apply generally to landlordism in Asia: "A high degree of tenancy is associated with unstable social conditions. Notable features are little respect for the law, lack of education, and poor farming practices. Neither the landlord nor the tenant gives much thought to the productive factor—the land. The tenant is unwilling to improve the land, for none of the value created by his efforts will accrue to him. The landlord is unwilling to improve the land, for he cannot trust the tenant. Thus, land improvement, with a corresponding increase in productive efficiency, does not and cannot take place in this unhealthy situation."

INDEBTEDNESS

In many cases the conditions under which the land is held by the cultivator are directly connected with the financing of the cultivation of the crop, but the landlord is not alone in taking advantage of the financial instability of the cultivator. Reports from almost every country in Asia provide evidence of the poverty of the cultivator and of his consequent heavy burden of debts, usually contracted at high rates of interest.

The Burma cultivator has fallen more and more into the hands of the moneylender to whom, in many cases, the ownership of the land has passed, so that now 44 per cent of the paddy-land is owned by non-cultivators, while of the 56 per cent who are owners, but few possess areas exceeding 100 acres. Landlords are not necessarily of the professional moneylending class—the Chettiars—but as they own little else than the land they rely on the Chettiars for cash advances as much as do the cultivators. The cultivator has to find money for current expenses, implements, seed, and for advances, shelter, and food for his labourers who possess nothing until the paddy is harvested. For all these expenses he looks to his landlord, who borrows from the moneylender, but if the cultivator is also the owner, he looks direct to the moneylender. Thus, most of the money lent by the landlord is borrowed from the Chettiar at $1\frac{1}{4}$ to $1\frac{3}{4}$ per cent per month, who lends this money to the cultivator at $1\frac{3}{4}$ to $2\frac{1}{2}$ per cent per month. Loans are repayable to Chettiars in cash, but landlords usually expect repayment from cultivators in paddy.

If the cultivator is unable to obtain loans from the Chettiar or the landlord, he is financed by traders and village shopkeepers who, because the risk is greater, charge higher rates, and insist on repayment in paddy, on which, of course, they make a further profit.

It is easy to imagine how wide is the interest in the crop at harvest time, everyone looking for the return of money lent, either in cash or in paddy. The cultivator, too, usually pays his labourers for work during the season in an agreed quantity of paddy.

The Burma Rice Marketing Section Survey Report[201] sums up the position in the following terms: "The main stumbling-block in the way of marketing progress is the cultivator's chronic state of financial embarrassment. If, in the improved-strain areas, relief from this could be given it should not be impossible to get the paddy unmixed to the primary assembly points. Here it could be graded, and could be sold under standardized and supervised conditions of weighing and measuring. The mutual distrust which finds present expression in adulteration on the one hand and chicanery in measuring and weighing on the other, might then be expected to give place gradually to a mutual interest in maintaining grade standards."

In India, Malaya, and the Philippines the plight of the cultivator is very similar; heavy indebtedness to moneylenders and shopkeepers and a complete absence of financial stability compel him to borrow at high rates of interest and to mortgage his land; this leaves him with very little of the fruits of his endeavours.

Indebtedness, however, appears to be less serious in Thailand. In the non-commercial paddy-growing regions indebtedness is not

usually heavy and interests are not unduly high. The legal limit of rate of interest is 15 per cent per annum and this is not, in fact, exceeded to any considerable extent. The rate of interest is also restricted by law in Malaya, but is evaded by the moneylender who may compel the borrower to sign for a greater sum of money than is actually borrowed. There are the usual arrangements of loans and repayments in Thailand, usually to the disadvantage of the borrower, but despite this, it is unusual for arrears of interest to be accumulated with the principal, nor are foreclosures for debt very frequent. Land and jewellery are the main securities throughout Asia, but in Thailand many loans are arranged without security.

In Indo-China the moneylenders are Annamites and Chinese, who are usually also local shopkeepers and/or dealers in paddy. Rates of interest charged by them are stated to be frequently very high—they may be anything up to 100 per cent per annum. Before the economic crisis in 1931–2, the majority of the paddy farms were mortgaged, but the position has since improved as a result of government regulations regarding interest rates, coupled with improvement in the market price of rice.

The Chinese farmer[33] is usually in need of ready money. This he obtains through the sale of crops which have a ready cash value. Furthermore, he often sells his superior food products such as wheat, and consumes inferior grain. To provide cash as well as home food products he has developed cropping systems designed to produce the variety of crops required and to utilize his labour throughout the growing season. The most important source of credit is relatives and friends, whose demands on the borrower are not usually extortionate. Short-term loans may be required for the purchase of fertilizers, implements, animals, and seed. Long-term credit for buying land is unusual, though money is sometimes borrowed to redeem mortgaged land. Farmers require money to carry on the work of their farms, but only about a quarter of the credit obtained is for productive purposes. Being without capital, the loan is usually required to supply family necessities until harvest.

The extent and seriousness of indebtedness varies throughout China. In many cases the owner tends to lose possession of his land to the moneylender and to become the tenant on his own land. Some farmers are badly in debt and usury in some districts is a serious problem. The credit is obtained from merchants, landlords, and shopkeepers, who often bleed the borrower to the limit. Rates of interest are high; in fact, in the Rice Region they average 28 per cent, but then the risks may be high—the danger of droughts and floods, of serious pests and diseases, and of bandits.

It is evident that the paddy cultivator in China suffers from very much the same financial and economic difficulties that beset his counterparts in the other paddy-growing regions in Asia. One can detect little evidence that a solution has been found for the problem thus presented in China, but owing to the great political upheaval in that country it is probable that the solution has been found on communist lines.

There is one important point of similarity regarding the indebtedness of the paddy planter in almost all regions in Asia—it is that the difficulty is caused less by the needs of the land for capital than by the thriftless nature of the planter. Given the capital, given the loan to tide him over till harvest, in many cases the money will be diverted from the purpose for which it was borrowed. The poverty of the paddy planter is not usually caused by the uneconomic conditions of cultivation or marketing, though they may contribute to his position; his poverty is caused almost invariably by his own improvidence. This must be appreciated if any fruitful endeavour is to be made to better his position. So long as the growers' attitude is as at present, any improvements resulting from new methods of cultivation, better planting material, or more efficient marketing organization will only add to the prosperity of the moneylender and the landlord. This fact has been too frequently overlooked in the past in connection with various schemes devised by governments to better the lot of the cultivator. There is no short cut to this betterment; the solution of indebtedness still depends on the personal efforts of the cultivators themselves—the will to become independent.

COST OF PRODUCTION

It is difficult to estimate with any accuracy the cost of production of rice, for the crop in Asia is usually cultivated with family labour working at uncertain times. A number of authorities have, however, examined this subject in some detail; their conclusions form a basis upon which one may construct a price-standard that could ensure the well-being of the cultivator and consequently the maintenance of the area under the crop in Asia. It is certain that if the financial returns from the cultivation of paddy are insufficient to ensure an adequate standard of living for the producer, the development of industry in other directions will result in widespread abandonment of paddy cultivation, which once started will be difficult to stem.

Leonard[139] gives the following interesting data on the labour required to produce an acre of paddy in (*A*) the Saitama Prefecture, and (*B*) of an acre of dry-land paddy in the Iberagi Prefecture of Japan.

(*A*) produces 49·6 bushels of brown rice or 86·4 bushels of paddy; (*B*) produces 21·2 to 25·5 bushels of brown rice or 36·9 to 44·4 bushels of paddy.

(*A*) *Wet rice*			(*B*) *Dry rice*		
	Man days	*Horse days*		*Man days*	*Horse days*
Growing seedlings	12·1	1·2	Harrowing ..	2·0	—
Ploughing ..	4·5	4·5	Fertilizing and sowing ..	8·1	—
Levelling ..	4·9	4·0	Cultivation ..	6·1	—
Transplanting ..	8·9	—	Weeding	16·2	—
Cultivation ..	13·0	—	Harvesting ..	12·1	1·2
Weeding	2·0	—	Drying	2·8	—
Harvesting ..	5·7	—	Threshing ..	12·1	—
Drying	1·2	—	Hulling	4·0	—
Transportation ..	0·8	—	Preparation ..	5·3	—
Threshing ..	6·1	—	Packing	2·0	—
Drying seed and preparation ..	18·2	—			
Packing for market	2·4	—			
Total ..	79·8	10·9	Total ..	70·7	1·2

It is difficult, however, to reconcile some of these figures; why, for instance, does it require 6·1 man days to thresh 86·4 bushels of paddy from the wet-rice area and 12·1 man days to thresh half that quantity from the dry-land area? It is to be noted also that no allowance is made for work in connection with irrigation.

Contrast the above estimate with that made in the Report of the Philippine Farmers' Committee on a Visit to the U.S.A. in 1946; that in the latter country two men can farm from 300 to 400 acres of paddy-land with the aid of two 35 h.p. tractors and thirteen other machines, including ploughs, harrows, levellers, drills, and harvesters.

Burgess,[34] writing of conditions in Thailand in 1940, states that the cultivator probably does not consider whether paddy-planting pays. From experience he knows that even in a bad season his food supply is secure, clothing and shelter cause him no anxiety, while if the crop is good and the market price favourable, he enjoys a cash income. This attitude probably applies in all cases where paddy is grown commercially in Asia. In Thailand, as elsewhere, the attitude is different where the land suitable for paddy is limited and where other and more remunerative sources of income exist.

The present writer made the following estimate of the cost in number of days required to cultivate an acre of paddy in the state of Negri Sembilan, Malaya.[92]

	Days' work		
	Men	*Women*	*Buffaloes*
Part cost of erection of dam or water-wheel	5	—	—
Waterways	1	—	—
Ploughing—first with buffaloes ..	10	—	10
Digging—by women	—	20	—
Fencing and preparation of nursery ..	4	—	—
Transplanting	—	12	—
Lifting seedlings from nursery and transport	1	—	—
Weeding and after-cultivation.. ..	10	—	—
Upkeep of waterways, dams, etc. ..	4	—	—
Harvesting	—	20	—
Totals	35	52	10

Cultural methods in Java necessitate much hand labour; the actual labour required depends on the nature of the soil, the irrigation conditions, and on the yield of grain. In one neighbourhood the figure is put at 100 days per acre.[83]

In British Guiana, using a pair of oxen and plough, about 37 man days are required. In this colony, however, the crop is little weeded if at all, and harvesting is performed with a sickle.

At the present time, when the price of rice is unusually high, it is fruitless to attempt to estimate the profit obtained by growing rice. Before the war, however, when prices were more stable, it was estimated that the gross income of the cultivator on the Central Plain of Thailand was about £12 per acre. The net income is difficult to arrive at as the work is usually performed by family labour.

The economic position of the cultivator depends less upon the actual price which he obtains for his paddy or rice than upon its purchasing power. Wickizer and Bennett[271] have shown that this purchasing power in some countries, and probably all countries of monsoon Asia, was substantially lower in the 1930's than in the 20's, and distress among the cultivators was certainly evident in the later decade.

THE POLICY OF SELF-SUFFICIENCY

In Asia, for some years past, there has been a growing realization that reliance on outside sources for rice constitutes a weakness in the social system; many efforts have been made to rectify this by various methods of increasing local production, aiming at making

paddy cultivation more attractive. Government intervention in the paddy-growing industry was inevitable, but in reviewing the results of the various expedients adopted to achieve this object one is forced to the conclusion that, considering the great effort and expense involved, in the majority of cases the results have been below expectation. Apart from projects designed to improve the lot of the producer by such means as improved water control, distribution of improved seed, creation of marketing organizations and the like, which may be considered justified in principle, the most usual method of intervention has been the far more doubtful one of manipulating the price of the product, either in the producers' favour or in that of the consumer—or both. The Japanese, for instance, for years attempted to control the price of rice. Wickizer and Bennett,[271] who review these manipulations in considerable detail, conclude that "after two decades of experience, the problem of satisfactorily reconciling the conflicting interests of Japanese farmers, producers in the colonies, distributors and dealers, and rice consumers generally does not appear to have been solved." They point to the great expense of the schemes devised by the Japanese Government in this connection, and conclude that "paying the producer the maximum price and selling to the consumer at the minimum, which amounts to direct subsidy to both, always results in a loss which the government must absorb."

The same writers also considered the efforts in the Philippines to control rice and conclude that this "experiment in rice control has apparently not as yet been seriously confronted with the irreconcilable facts that higher prices for the rice grower mean more expensive rice for the consumer."

One is drawn to the conclusion that, necessary as price control may be during a crisis, as a normal means of improving the lot of the producer, of protecting the lot of the consumer, or of attempting to increase production, it is unsound, both morally and economically. Wickizer and Bennett remark that the steps to ameliorate the unfavourable economic position of the rice grower in monsoon Asia "that have been taken by governments seem hardly to have touched the fundamental circumstances of rural poverty. Perhaps," they conclude, "the problem is beyond the reach of governmental agencies, or perhaps most of the countries of monsoon Asia can ill afford a drain on national treasuries or a burden on consumers of a magnitude sufficient to raise appreciably the incomes of domestic rice producers." These writers are apparently attracted by some of the more grandiose schemes for rice control which have been proposed, but it is not clear that they are fully aware of some of the more

unobtrusive work which has slowly developed, aimed at improving the lot of the cultivator with the minimum of governmental interference. It is true that complete self-sufficiency has never been attained in any of the rice-importing countries of Asia, but a very close approximation to it was attained under the Dutch regime in Indonesia and it seems not unreasonable to hope that its solution may be possible in some other Asiatic countries.

FINANCING THE CULTIVATOR

Co-operation in the East

There can be no question that measures for improving supplies of irrigation water and the control of water in rice-fields, the improvement of paddy varieties, the introduction of better cultural practices, including manuring, and research leading to greater knowledge of the requirements of the rice crop are essential for increasing production. Nevertheless, apart from these considerations the greatest obstacle to increased production, especially among the peasant cultivators of rice in the East, is the inadequate financial resources of the cultivator. Consequently some brief discussion of this aspect is necessary and in examining it is useful to contrast the position as it exists in the East with that in the rice-growing areas of the United States of America, where a high degree of organization in this regard has been built up.

It has become accepted that the remedy for the evils and difficulties which beset the small grower, not only of rice but also of other crops, is the introduction of the co-operative principle, and many efforts have been made to introduce co-operative methods among communities of small cultivators not only in the East but also in other parts of the world, based on the success which has attended similar efforts among smallholders in many of the countries of Europe.

These efforts were in the first instance directed mainly to providing financial assistance, but latterly they have been extended to the marketing of produce, the purchase of supplies, and more recently still it has been proposed to apply co-operative methods to the collectivization and cultivation of smallholdings. The beginnings of co-operative finance in the East were in India and took form with the passing of the Co-operative Credit Societies Act of 1904, subsequently amended by another Act in 1912. It subsequently extended to a number of other countries, including Ceylon, Burma, Thailand, Malaya, Indo-China, Indonesia, and China.

It cannot, however, be said that, except in a few places, it has made

any really effective contribution towards solving the difficulties of the small cultivator.

In India progress was rapid in the earlier stages; by 1927 65,000 agricultural credit societies had been registered with a total membership of 2,175,000; their activities covered all forms of peasant agriculture, including rice growing. It will be seen, however, that bearing in mind the size of the population of India, which at that time was approaching 300 million, they affected only a small fraction of the total. Moreover, even at that time many difficulties and shortcomings had become apparent. The societies were for the most part of the unlimited liability type, following the principle of Raiffeisen, which is based upon pledging the credit of all members to the limit of their resources as a security for money borrowed. For success it demands the utmost punctiliousness on the part of members in repayment of loans and honouring their obligations, combined with strict adherence to and understanding of co-operative principles, which are by no means completely simple.

In India the movement has been the subject of repeated committees and commissions of inquiry. As long ago as 1925 the Oakden Commission reporting on the movement in the United Provinces found that "the village society was mostly a sham, the principles of co-operation were not understood and the staffs were unfit for the work they were supposed to do."

Commenting on the position in 1928 the Royal Commission on Agriculture in India remarked: "for these disquieting conditions lack of training in and understanding of co-operative principles was the most important cause. The democratic principle is not so potent a force in checking abuses as is sometimes supposed. Members take insufficient interest in the working of their society; they exercise little restraint over their president and committee, and hesitate to evict from office an incompetent or dishonest neighbour. Office holders on their side dislike incurring the unpopularity attendant on stringent action against recalcitrants and the recovery of overdue debts by legal processes."

The Commission concluded: "the only remedy which appears to offer any sure prospect of success is the patient education of the members of primary societies in the principles and meaning of co-operation by teachers competent to perform the task under adequate supervision."

Since then experience in many other countries has emphasized and confirmed this dictum. The success which has attended individual efforts among backward communities where these principles have been rigidly applied, shows beyond any doubt that co-operation

has inherently the power greatly to improve the lot of small cultivators in primitive conditions, but the circumstances and the mental outlook of the people themselves make the task one of considerable difficulty.

Among efforts to improve the economic position of small paddy planters mention may be made of the establishment by the Dutch in Indonesia in 1900 of what were termed "dess lumbungs" or village granaries. They accepted for storage surplus paddy, and lent paddy to be repaid in kind at harvest time. A parallel development was the "dessa" banks or village banks which made small money advances. Both types were under the direction of village headmen, and were supervised by the Algemeine Volkscrediet bank, organized in 1934, which also made somewhat larger loans to cultivators. Attempts were made to introduce co-operative principles into the working of the "dessa" banks but without much success. There was also provision for Native Co-operative Societies, and Government Regulations were enacted for their registration and conduct. In 1935 some 300 societies were in existence, mostly credit societies, but with an increasing number of producers and marketing societies.

In Thailand, a Co-operative Department, established about thirty-five years ago, organizes Rural Credit Societies. Money is obtained by the societies at 6 per cent and loaned to members at 12 per cent, the loans being utilized mainly for the purchase of land, stock, and equipment, though the society may also settle a member's debts on the security of his land. Loyalty of the members to the societies and the regularity of repayment of debt are said to be very satisfactory. A society is usually ready to accept paddy in payment of debt, and societies are now entering into the paddy-buying business.

In Indo-China the co-operative movement had been working for but a few years before the outbreak of war in 1941, but progress was recorded. Through such societies growers have contracted to grow improved strains of paddy supplied by the Bureau du Riz and to entrust the selling of the crop to the societies. Each member receives a cash payment on surrendering his paddy to the society and final settlement is made when all stocks held by the society have been sold. The scheme ensures that large stocks of one approved variety are marketed, and this uniformity enables the society to obtain a satisfactory price. Rural Credit Banks have been formed and serve a useful function in advancing loans to cultivators and in supporting the campaign to increase the use of fertilizers by furnishing credit for their purchase.

In Malaya various efforts have been made to relieve the cultivator of his financial burden. Government rice mills are in operation in

competition with the Chinese-owned mills, with the object of stabilizing prices paid for paddy at the mill, and the minimum price for paddy is guaranteed by the government. The Co-operative Department has laboured steadily for some years to inculcate the idea of thrift amongst the cultivators. Short-term or seasonal credit is the great need of the cultivator. Usually he obtains such credit from shopkeepers, but this accommodation proves expensive, for the security demanded is usually the crop, which has to be sold to the creditor at an agreed price below the market price. Efforts have been made to organize the smallholders into co-operative credit societies with a view to providing a seasonal credit more beneficial to the producer. In many cases such societies have been most successful—so long as they restrict their operations to the supply of seasonal credit, but many get into difficulties by using funds designed to supply short-term credit for long-term purposes, such as the redemption of mortgages.

To sum up, it can be agreed that, subject to the limitations already indicated, co-operative methods offer the greatest promise of providing a solution to the economic problems of the small grower.

Co-operation in the United States

Efficient and well-managed growers' co-operatives have operated in all the paddy-growing areas of the United States[14] for many years, and have co-operated closely with various governmental programmes relating to the crop. Before enactment of crop-control legislation in the early 30's, the co-operatives were already exercising some control over members' production by limiting credit to growers. Through close contact with producers, the co-operatives have been able to exert an important influence on members in other ways. They advise growers regarding the probable supply and demand, supply them with seed paddy, fertilizers, and machinery, furnish irrigation facilities and credit, set up mills, sell the produce, and provide storage pending sale of the rice.

No one co-operative performs all these services, for growers' preferences in this respect are not the same in all paddy-growing areas. In each area, therefore, the growers determine which services incident to the production and marketing of the crop shall be undertaken co-operatively. The annual volume of rice handled co-operatively in the United States is stated to be between 25 and 30 per cent of the total production.

Early paddy-growers' organizations have been succeeded by the present American Rice Growers' Co-operative Association, which functions through fourteen member-locals, and operates eleven

co-operatively owned warehouses for storing paddy, a credit association, an irrigation company, a land-leasing corporation, and a farm supply-buying organization. Two paddy-grading laboratories are also maintained to enable a thorough check on the quality and condition of rice which its members offer for sale. The policy of informing growers regarding all aspects of the marketing situation is said to have contributed much to the excellent relations between members and the Association.

The "locals" operate as separate entities, select their own officers, and retain possession of revenues derived from membership fees or other assets acquired by them. Individual growers in areas served by incorporated locals sign marketing agreements with their respective locals, which in turn have a contract with the central association.

In Texas the grower is financed by the Association through the Gulf Coast Credit Corporation, the primary purpose of which is to provide working capital to produce the crop. It also makes loans for harvesting, storage, and marketing, and is prepared to make advances to growers on their rice pending sale. The Houston Division of the Association owns and operates an irrigation system which supplies water to some 45,000 acres.

An outstanding development in co-operation in recent years has been the ownership and operation of modern and up-to-date mills for the processing of their members' rice in California and Arkansas. The Arkansas Rice Growers' Co-operative Association now owns three mills, and also owns and operates warehouses with a total storage capacity of about two million bushels of rice. The Association markets only rice grown in Arkansas by the members. The grower may receive up to 75 per cent of the value of the paddy on delivery to the Association, and when it is milled an additional advance is made to him.

The Rice Growers' Association of California owns and operates a large rice mill, thoroughly modern in every respect. In addition to its rice-milling and marketing functions, the Association aids its members in financing their paddy crop.

It is a feature of all rice association activities in the United States that members retain control over affairs by election of the directors and by regional representation on the controlling boards. A second feature is that close touch is maintained between the associations and the members, and every effort is made to keep the latter fully informed of the progress of the affairs of the association and of the fluctuating marketing conditions. Thus, while government requirements are largely implemented by the associations, the members

give ready co-operation by reason of the smooth working of the machinery of control.

The results of co-operation in the U.S.A. are so striking that they need no comment; obviously if parallel developments could be brought about in the paddy-growing regions of Asia it would go far to solving many of the problems. Admittedly in the U.S.A. the units cultivated are individually much larger, while the growers are far better educated, have a wider and more informed outlook and a far higher standard of life. Nevertheless, if the Eastern cultivator could be brought to understand and put into practice co-operative principles and methods with their inherent limitations and restraints on individual freedom of action, it could not in the long run fail to produce striking results.

BETTERMENT OF ECONOMIC CONDITIONS

In most countries in Asia there is appreciation of the fact that the well-being of the country depends in no small measure in maintaining and even increasing the production of rice. On the one hand, the cultivation of paddy must be sufficiently attractive to the producer; the price to the consumer must be as low as possible, for in the East the cost of living and therefore labour rates of pay depend largely on the price of rice. The solution of this problem of greater profits for the producer and cheaper rice for the consumer can be solved—not by government control of prices as has been attempted in Japan—but by increasing the yield per acre and decreasing the cost of production. The efforts to increase yields have already achieved some success and further advances in this direction may be expected. Further, mechanization of some, at least, of the operations of cultivation will lower cost of production. There remain, however, other problems: unsatisfactory conditions of tenancy, antiquated laws of inheritance (especially those that result in fragmentation of lands), and the financing of the cultivator. Fragmentation can only be solved by somewhat ruthless alterations in the law and by adjustments in individual holdings. As regards finance, it must be admitted that most of the trouble is due less to the lack of money to finance the cultivation of the crop than to the thriftlessness, improvidence, and individualism of the cultivator. While this continues, co-operative societies will have but a limited success. The cultivator must learn thrift, and the initial effort of co-operative departments, aided, let it be hoped, by improved education, must be to teach the necessity for thrift. The problem may be stated in another way; while government aid in improved irrigation and drain-

age, provision of good seed, better marketing facilities and the like, may encourage the cultivator, the policy of "something-for-nothing" does not pay; people in the Orient, as also in the Occident, appreciate the things they have to pay for more than those that are free. The salvation of the paddy cultivator depends on himself, on his own efforts to free himself from financial embarrassment; this he may achieve through education and co-operation. This has been stated by one authority in the following words:

> It is the fundamental principle of all co-operative activity that material progress is of little avail without a corresponding educational advance in self-reliance, responsibility, and citizenship. But once the stage of governmental assistance in guidance and education has been passed, the co-operative movement in any Colony should proceed on its own momentum as a dynamic people's movement. It will then produce its own leaders and educationists from the ranks of its own members, and gain confidence, experience, and ability with each step forward.[214]

Appendix

THE SCOPE AND WORK OF THE INTERNATIONAL RICE COMMISSION

THE Food and Agriculture Organization of the United Nations early recognized that the world's most insistent problem is that of expanding rice production, for not only is rice the staple food of about half the human race, but the daily diet of almost all the peoples of south-east Asia is based on this cereal. By 1950 total rice production had regained pre-war levels, but the *per capita* rice consumption levels in the East remained seriously low, because the total population of the areas had increased about 10 per cent since 1937. It was evident that early action should be taken to increase the total production of rice. This urgency for increased production was appreciated by Asian governments, and individually they were pursuing investigations towards this end. It was considered, however, that much greater progress would be made if these governments pooled their knowledge and planned overall rice programmes. Consequently, in May 1947 a group of rice experts from ten countries met under F.A.O. auspices at Trivandrum, India, to study these problems. Their pooled knowledge and recommendations, which covered a wide field, were summarized in the *Report of the Rice Study Group, Trivandrum, India*, 1947, an F.A.O. publication.

The F.A.O. Conference at its third session, August 1947, noted the recommendations of the Study Group and authorized an international meeting at governmental level to consider putting them into effect. Accordingly, a Rice Meeting was convened at Baguio, Philippines, in March 1948. The nineteen government representatives present made concrete recommendations to governments concerning rice improvements as previously outlined by the Study Group. In order to maintain a continuing rice improvement programme internationally, the Baguio meeting recommended the creation of an International Rice Commission. The establishment of such a body within the framework of F.A.O. was approved at the 1948 session of the F.A.O. Conference. The International Rice Commission was established in 1949 with a membership of seventeen nations, and held its first meeting in Bangkok, Thailand, in March 1949. The Commission is the first international body having the

express function of studying the problems of production and consumption of rice.

The Rice Commission recognized the improvement of rice varieties as the most essential and direct method available to many countries as a means of increasing yields. Consequently, at its first meeting the Commission set up a Rice Breeders' Working Party to co-ordinate the activities of scientists working on this problem. This Working Party held its first meeting in Rangoon, Burma, in 1950, and its second in Indonesia in April 1951.

Following the Rangoon Meeting, a co-operative project, to be carried out by the Central Rice Research Institute at Cuttack, India, has as its object the hybridization of Indica and Japonica types of rice, the seed being contributed by co-operating countries for experimental crossings. The Institute will send seed of hybrid lines to the other rice-breeding stations participating in the project, where successive generations will be grown and selections made in order to secure better adapted varieties under local conditions of soil, climate, disease, and pest hazards.

One of the advantages of a hybridization programme is that through crossing and selection a variety can be produced which meets the particular needs of a certain region. Thus in crossing for new varieties of rice, parents will be chosen to fit the specific requirements of each participating country, be it resistance to disease or pest, the need for a strong straw, a variety that does not shatter, or any other character.

The primary aim of rice breeding in Asia is increased yield, but the value of improved varieties can only be realized to the extent to which they are used by cultivators. It has been estimated that yields in most of the rice-producing countries could be increased by 10 per cent if seed of the best varieties now available were generally adopted. A well-organized pure-seed production and distribution programme is therefore a prerequisite to the extensive use of improved seed by cultivators. Many countries are weak in this respect, or they lack any effective method of raising the general level of seed supplies. The question of how best to secure a wider use of good seed is one of the problems engaging the attention of the Rice Breeders' Working Party.

While plant scientists in south-east Asia, working individually, have done much to improve rice standards, it is recognized that more may be done if they work as a team through international co-operation. The F.A.O. therefore has assisted in a regional plan to bring all branches of plant science together for a concerted attack on rice production problems. Plans are also being developed for a

training centre for rice breeders in south-east Asia. This centre will provide young workers with an opportunity to become acquainted with modern techniques and recent advances in plant breeding.

Realizing the great possibilities in the use of manures and commercial fertilizers for increasing rice production, the International Rice Commission established at its 1950 meeting a Working Party on Fertilizers, which held its first meeting in Indonesia in April 1951. A working paper on the experimental work under way on fertilizers in Asia has been published which summarizes the experimental results and evaluates methods used for determining fertilizer needs. It also gives summaries, by countries, of experimental work on fertilizers and manures, and the use of these materials by cultivators.

In some rice-producing countries, experimental work has been done on fertilizers and manures, including green manure. Some, but not all, of the experiments have been summarized. By bringing together the technicians carrying on the work in different countries, the Working Party on Fertilizers expects to obtain a clearer picture of work already done and show how the experiments can benefit the rice economy, especially in countries where little experimental work has been conducted. The Working Party will also determine what are the main gaps in knowledge in rice areas for the most effective use of fertilizers and manures, and will outline the problems which need to be solved.

The Working Party will provide an opportunity for scientists of different countries to compare methods used in their experiments. They will examine the possibility of making more extensive use of soil-analysis methods, especially quick tests, for determining fertilizer requirements on different soils. Consideration will also be given to such problems as the training of local technicians; of bridging the gap between knowledge and practice; and of finding ways and means of getting more cultivators to use more fertilizers and manures more effectively.—*F.A.O. Fact Sheet, No. x*-1, 2 April 1951.

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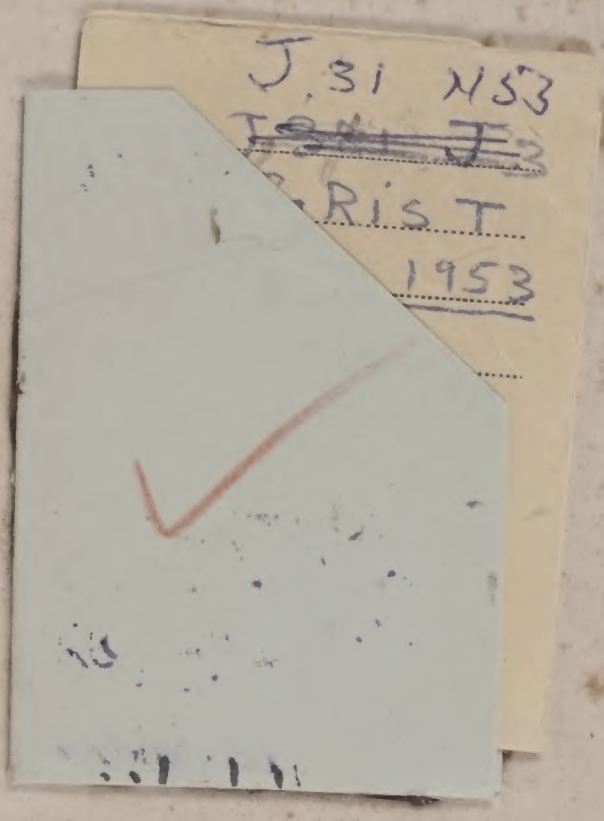
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